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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXXIV.

SESSION 1871-72.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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7763

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
1872.

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LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1871–72. Part II.

February 13, 1872.

GEORGE WILLOUGHBY HEMANS, Vice-President, in the Chair.

No. 1,322.—"Account of the Bridge over the Gorai River, on the Goalundo Extension of the Eastern Bengal Railway."[1] By Bradford Leslie, M. Inst. C.E.

Of the numerous deltaic branches through which the water of the Ganges flows to the sea, the Gorai is the largest and most important. It is more uniformly deep than the Ganges proper, and towards the end of the dry season, when the rise of the Burhampooter keeps back the main stream, it discharges a larger body of water into the sea. It is in fact the large volume of fresh water poured down by the Gorai river, or, as it is called lower down, the Huringotta river, that has rendered possible the establishment of the new port of Morelgunge within 40 miles of the sea, being the most advanced outpost in the vast tract of land bordering on the sea, called the Sonderbunds, the greater portion of which still remains unreclaimed, chiefly owing to the difficulty of obtaining good fresh water.

The Gorai river is also the main navigable channel through which, in the dry season, the produce of the upper districts is brought down to Calcutta, by country craft and inland steamers.

At the site of the bridge the river in the dry season is about 1,000 feet wide, with a depth of water of 40 feet, and a stream of

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

3 miles an hour. The width is increased to 1,600 feet in the rainy season, when there is a rise of 28 feet, and the velocity of the stream becomes nearly 5 miles an hour, causing the bed of the river to be deepened 24 feet, so that the depth during the floods is upwards of 90 feet.

Approach Viaduct.

The deep channel is on the east side of the river. On the west side there is a sandbank 500 feet wide, which is dry in the cold season, and has about 30 feet of water over it in the floods. This part of the river is crossed by a screw pile viaduct in nine spans of 46 feet 3 inches, and one half span. Each of the piers consists of two cast-iron piles carrying the superstructure, strengthened by two auxiliary piles connected with the centre piles by wrought-iron bracing. The piers of this viaduct are so arranged that, if rendered necessary at any future time, by an alteration of the deep channel threatening the stability of the viaduct, the main bridge can be extended in this direction, without removing the viaduct or interrupting the traffic.

Main Bridge.

The main bridge consists of seven spans, of 185 feet each from centre to centre, carried by eight piers: six spans cross the low water channel of the river, and the seventh is a land opening on the east side.

Piers.

Each pier is composed of two cylinders, placed 37 feet 6 inches apart, from centre to centre, and thus wide enough to carry the superstructure for a double line if required. Those on the west side of the river are sunk to a depth of 80 feet, and those on the east side, where the water is deeper, to a depth of 98 feet below low water. The piers of the land opening are sunk to the same depth as those in the river, so that in the event of the river encroaching on its bank, the cylinders will not be in danger of being undermined.

The cylinders (Plate 8) have each a wrought-iron base, 30 feet 6 inches high, 14 feet in diameter at the bottom and 13 feet 4 inches in diameter at the top, above which a cast-iron taper piece or cone, 9 feet high, reduces the diameter of the upper portion of the cylinder, which is also of cast iron, to 10 feet. The wrought-iron portion of the cylinder consists of a bottom ring 3 feet 6 inches high, and six upper rings, each 4 feet 6 inches in height. The

lower edge of the bottom ring is strengthened by two extra plates, so as to form a strong cutting edge, and each of the other rings is strengthened by a diaphragm at the bottom 15 inches wide. The rings are bolted together by internal angle-iron flanges, and all the joints caulked with cement. As the cylinders were erected, a ring of brickwork was built on each diaphragm. The cast-iron portion of the cylinder is composed of segments, four segments to each ring, of 10 feet in diameter and 9 feet in height, excepting the taper piece or cone connecting the wrought-iron base with the upper portion of the cylinder, which is made in eight segments. The segments are bolted together by means of internal flanges, and the joints caulked with cement. The cylinders, when finished, were filled with concrete and brickwork; and the two cylinders of each pier were connected at the top by two wrought-iron cross girders, which carry the main girders of the superstructure at a height of 22 feet above high-water, or 50 feet above low water.

Superstructure.

The superstructure is for a single line of railway, and occupies the northern half of the piers.

The main girders are solid beams 12 feet 6 inches deep between the top and bottom tables, which are 3 feet wide. The main girders are placed 13 feet 6 inches apart in the clear. The railway consists of bridge rails resting on longitudinal baulks of timber, carried by transverse flooring girders 18 inches deep, placed 5 feet apart, from centre to centre, and resting on the bottom flanges of the main girders.

The expansion and contraction due to variations of temperature take place on the 1st, 3rd, 6th, and 8th piers, on which the bed plates are covered with brass plates to diminish friction. The girders are connected (though not so as to transmit the strain as in continuous girders) over the 2nd, 4th, 5th, and 8th piers. As the rails move with the girders, a scarf joint in the rails admits of the adjustment consequent on expansion or contraction.

Appliances for Working.

Owing to the treacherous nature of the bed of the river, the great depth of the water and the strength of the stream, it would have been very difficult to erect a staging for sinking the cylinders; and even if this had it been possible in the dry season, it would have been necessary to remove the staging and to stop the work

during the floods, when the depth of the water and the force of the stream increase so greatly.

It was therefore more convenient to sink the cylinders from pontoons moored at the site of the piers.

Pontoons.

For this purpose a pair of pontoons was provided (Plate 9), each 140 feet long by 30 feet beam, by 7 feet deep, connected together at a distance of 17 feet by an intermediate platform, with openings corresponding to the distance apart of the two cylinders of a pier. The intermediate platform was not fixed rigidly to the pontoons, but was hinged to them in such a manner as to admit of independent vertical motion in the pontoons, though not allowing any freedom of motion in a horizontal direction. The pontoons were each strengthened by two fore-and-aft and two transverse bulkheads by which they were divided into nine compartments. The pontoons were furnished with two powerful travelling cranes, 37 feet span and 25 feet hoist, travelling on rails laid fore and aft on each pontoon, so that the travelling cranes commanded the whole space between the pontoons and a portion of the deck of each. One of the pontoons was also fitted with a 20-H.P. engine, for driving two 13-inch Appold centrifugal pumps, and a pair of air-compressing and exhausting pumps, provided for working the appliances used for sinking the cylinders.

The pontoons were also equipped with two powerful capstans each, besides bollards, fairleaders, &c.

The pontoons were moored at the site of the pier by chain cables from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches diameter, and anchors from 21 cwt. to 40 cwt.; one mooring of 45 or 60 fathoms being laid out from the bow, and one from the stern of each pontoon in an oblique direction, so that the four moorings formed in plan a St. Andrew's cross. To keep the pontoons perfectly steady at the site of the pier in so strong a stream, it was necessary to strain the moorings very tight; this was effected by one-inch chain tackles set tight by the capstans.

Anchor Boats.

For laying the moorings and picking them up again a pair of anchor boats was prepared. These vessels were each 40 feet long by 12 feet beam, and were rigidly coupled together by a timber truss 13 feet from the bow, and by a strong baulk of timber near the stern, at a distance of 8 feet apart in the clear between the two boats.

The boats were equipped with rollers, chain stoppers, bollards, sliphook, stoppers, capstans, cathead, &c., for laying the moorings, and with a very powerful crab winch and chain tackle for heaving up the anchors. The rollers leading the chain inboard were fixed between a pair of hardwood bitts fitted to the forward truss, which being one-third of the boat's length from the bow, gave them much greater lifting power than ordinary anchor boats, in which the roller is generally fixed to a horn projecting from the stem of the boat. Moreover, the boats were provided with water-tight bulkheads under the forward truss; so that the fore part of the boats being depressed by admitting water, and the chain cable hove "taut," by pumping out the water the full lifting power of the boats was made effective for breaking the cable or anchor out of the sand.

Pitching the Cylinders. (Plate 8.)

As the depth of the water was greater than the hoist of the travellers, it was not possible to sling a sufficient length of the cylinder to reach the bottom at one operation; besides which the weight would have been too great. The three lower rings of the cylinder were erected on baulks of timber laid across the opening of the platform; a ring of brickwork 15 inches thick was then built on the diaphragm in the second ring, and a temporary bottom, consisting of an inverted cone of taper pine-wood staves, the upper ends butting against an inverted angle-iron rivetted to the inner edge of the diaphragm at the bottom of No. 3 ring, and the lower ends butting on a central cast-iron plug, was fitted at the bottom of the third ring. Before the cylinder was lowered into the water, and until the pressure of the water was sufficient to support it, the cast-iron plug was suspended by a hook-bolt and cross beam laid across the inverted angle-iron above mentioned. Great care was required to make the temporary bottom perfectly tight by caulking the under side.

For lifting the wrought-iron portion of the cylinder, which varied from 14 feet to 13 feet 4 inches in diameter, a teak wood toggle-beam, with wrought-iron adjusting plates, and provided with two shackles corresponding to the least distance between the two purchases of the traveller, was used. The advantage of the toggle-beam, as compared with chain slings, was the saving of hoist, combined with greater safety.

When the three lower rings of the cylinder with the temporary bottom, weighing about 30 tons, had been lifted by the traveller,

the timber baulks were removed from beneath the cylinder, and it was lowered 8 feet into the water.

The cylinder moorings, for controlling and adjusting the position of the bottom of the cylinder as it went down, were then made fast to it (Plate 9). These moorings consisted of an up-stream 40-cwt. anchor and 45 fathoms of 2-inch chain cable, and two quarter moorings, consisting of 21-cwt. anchors and 1½-inch chain cable, laid at an angle of 120° with each other and with the up-stream mooring, the three moorings in plan forming the figure of the capital letter Y, the foot of the letter representing the up-stream anchor, and the intersection of the arms the position of the cylinder. The moorings were attached to the cylinder by means of a sling-chain or girdle fixed round the cylinder, 9 feet above the bottom (Plate 8), with which the mooring chains were connected by chain tackles; the hauling part being brought on deck, by heaving on two of the tackles and paying out on the third, or by heaving on one tackle and paying out on the other two, the bottom of the cylinder could be moved in any direction required. This plan of mooring the bottom of the cylinder was very efficient, and afforded complete control over it. On one occasion, in hauling on the up-stream mooring, it suddenly slacked up, and the cylinder, which was drawing 30 feet of water, was canted over by the stream, and began knocking about violently, so much as to break one of the cross girders of the intermediate platform. Fortunately the anchor had only slipped off a ledge of clay into deeper water, and by taking in the slack of the tackle the mooring was again tightened, and the cylinder steadied. When the cylinder moorings were connected, the cylinder was further lowered, until about 1 foot of the third ring was out of water, and in this position the cylinder was partially afloat and partially suspended, by auxiliary chains hooked on to the bottom of the cylinder, while the fourth ring was bolted on. The cylinder was then lowered 3 feet more, until it was quite afloat, the cylinder mooring chains were hauled tight, and the auxiliary hook chains cast off. The fifth ring was next bolted on, and the internal cylinder of brickwork carried up flush with the 15-inch diaphragm. As the weight of the brickwork depressed the cylinder, the remaining wrought-iron rings and the cast-iron conical ring were bolted on, care being taken to adjust the position of the cylinder by means of the moorings as it went down. On reaching the bottom of the river, the cylinder was filled with water by a syphon, and (the hook bolt and cross beam having been previously removed) the temporary bottom was driven out by battering it with rails suspended to a rope until the

staves were loosened, and floated up, and the central plug was pulled up by a buoy chain provided for the purpose. In pitching the first cylinder some inconvenience was caused by the temporary bottom leaking, which necessitated pumping night and day to keep the cylinder from sinking too soon.

When the cylinder was completed to the top of the conical length, and the internal brick cylinder built in the lower or wrought-iron portion, the bottom of the cylinder had just reached the bed of the river; and as the top of the cone was 9 feet out of water, it was determined to stop pumping and allow the water to leak into the cylinder during the night, with the expectation that the cylinder would soon begin to derive some support from the river-bed. Before morning, however the watchman reported that the cylinder had continued to sink, and that there was only a length of 2 feet of the cone left above water. There was only just time to prevent the cylinder going down altogether by getting the first 10-feet ring bolted on, and the "regulating" girders fixed across the top of the cylinder, and blocked up from the pontoons. As the water leaked into the cylinder it became evident that it was pitched in a quicksand, and derived little or no support from the bed of the river—that it was, in fact, hanging to the pontoons by means of the regulating girders. It was at first attempted to lower the cylinder gradually by the travelling cranes, and the hydraulic and screw jacks, but the weight (upwards of 100 tons) was too much for the gear that could be applied, the aggregate lifting power not being sufficient to weigh the cylinder while the blockings were changed. It was then decided to erect the second 10-feet ring, and take the weight of the cylinder on four raking shores, with their heels resting on greased sills, and held fast by dog-shores. When these arrangements were complete the dog-shores were simultaneously struck away by battering-rams; the pontoons, released from the weight of the cylinder, jumped up, and the cylinder dropped 4 feet on to the solid bed of the river.

The experience gained by the first cylinder enabled the temporary bottom to be made quite water-tight in all subsequent operations, so that in each case the cylinder continued to be water-borne until it was quite certain that ground sufficiently solid to bear its weight had been reached.

In driving out the false bottom, a few blows of the suspended rails were sometimes sufficient to loosen the staves, while at other times it was several hours before it could be removed.

Sinking the Cylinders.

The alluvial deposit of that part of Lower Bengal comprising the site of the bridge generally consists, near the surface, of clay, with a sufficient admixture of sand to render it suitable for brick-making. Lower down loamy earth, sand, and clay, are met with. At a depth of from 20 to 50 feet below the surface a stratum of dense dark-coloured clay occurs, which is very impervious, and yields but slowly to the disintegrating power of water; in fact, this clay seems to replace the rock of older formations in acting as a barrier to limit the range of the Ganges. The surface of this clay, when laid bare, is, in some places, studded with decayed stumps of trees in situ as they grew, and at other places is intersected with low banks, or "bunds," identical with those used by the natives as landmarks at the present day; and remains of pottery are also plentiful at this level, proving that it was, at some not very remote period, the upper surface of the country. The stratum of clay is of variable thickness, and very irregularly distributed. In many parts of both the existing and former beds of the Ganges and the Gorai rivers it is wanting altogether. Below the hard clay is a coarse, compact, grey sand, mixed with a few shells and pebbles, and intersected with thin seams of indurated sand, but without any remains of pottery. This sand is an excellent foundation, so far as carrying weight is concerned, and resists the scour of a moderate stream, but it is liable to be removed by a strong stream, or to be scooped out into holes by violent eddies, such as are caused by the piers of a bridge.

The depth to which the cylinders were sunk was fixed with reference to the probable amount of scour which might be anticipated. The first cylinders were sunk to a depth of 80 feet below low water, or about 40 feet into the river-bed; but the effect of the floods indicated the advisability of going to a somewhat greater depth, and, consequently, the remaining cylinders on the east side of the river were sunk to the depth of 98 feet below low water; and the experience of the very high floods of last year has shown that it will be necessary to protect those cylinders which are only 80 feet below low water, by surrounding them with a bank of heavy ballast.

For the operation of sinking the cylinders, the pneumatic (plenum) process might have been used. The objections were that it would have been necessary to suspend operations during the floods, or to have been prepared to carry on the work under a head of 100 feet of water or upwards. The difficulty of making

the cylinders tight under this pressure would have been considerable, and would have necessitated stronger cylinders and more numerous bolts, adding greatly to the cost. Moreover, the high temperature developed when air is compressed more than three atmospheres would have made it very trying to the workmen; besides which Coolie labour, requiring at least three men to do the work of one European, is ill adapted to cylinder-sinking by the pneumatic process demanding the maximum amount of work with the smallest consumption of air.

The system adopted for sinking the cylinders was by excavating the earth from the inside of the cylinder by a kind of rotary plough, or, as it was called, a boring-head (Plate 9), consisting of a horizontal disc-plate, with four blades at right angles to each other, projecting vertically beneath the under side of the disc-plate. These blades were triangular in shape, and armed with cutters, or ploughs, so that, in revolving, the boring-head excavated a conical hole 9 feet in diameter.

This boring-head was bolted to the bottom of a vertical shaft, consisting of an annular pipe of 13-inches inside, and 26-inches outside diameter, in 9-feet lengths, bolted together by outside angle-iron flanges. The space between the inner and the outer pipes was made air-tight by annular flanged plates rivetted into the ends of each length of pipe. The shaft thus formed a vertical pipe, surrounded by a series of air-jackets, the object being to combine great strength to sustain torsion with buoyancy in water. The shaft with the boring-head at the bottom was held concentric with the cylinder by top and bottom guide-frames, in which it was free to revolve. The guide-frames moved vertically on four vertical guide-rails or ribs, cast on the inside of the cast-iron segments of the cylinder, and continued at the same gauge by four vertical bulb-irons, bolted inside the conical and wrought-iron portions of the cylinder.

The boring-head was worked by a small compressed-air engine (Plate 8), assisted by hand-gear driving a pinion gearing into a large spur-wheel bolted on to the top of the boring-shaft. The pinion-shaft was a square bar 15 feet long, sliding vertically in the second spur-wheel, by which means the boring apparatus admitted a range of $12\frac{1}{2}$ feet vertically, independently of the cylinder.

As already explained, the annular shaft, whatever might be its length, was self-supporting in water. The weight available for forcing the cutters into the earth was the constant weight of the boring-head, guide-frames, &c.; in addition to which, for cutting very hard clay, it was sometimes necessary to fill one or two lengths

of the annular pipe with water; but for boring the ordinary earth and sand the boring-gear was kept partially suspended to the travelling-crane, by chains attached to the upper guide-frame.

The object of making the boring-shaft in the form of a hollow pipe was for removing the earth by a current of water constantly flowing up the pipe. For this purpose a 12-inch syphon-pipe was provided, the inner leg of which was immersed in the boring-shaft and the outer leg in the water of the river. The requisite current up the hollow boring-shaft was obtained by pumping water into the cylinder to a higher level than that in the river; then, by connecting the suction of the air-pumps with the syphon, the air was exhausted from it, and being replaced by water, a flow of water from the cylinder into the river was immediately established, proportionate to the quantity thrown into the cylinder by the two 13-inch centrifugal pumps.

The ordinary speed of the boring-head was one revolution in about a minute and a half or two minutes; and the average amount of boring done was about 1 foot an hour. It usually took one day to sink the cylinder 9 feet, and the next day to remove the driving-gear and syphon, bolt on the additional segments of a cast-iron ring, caulk the joints, refix the driving-gear and syphon ready to start boring again on the third day. The average daily amount of sinking was thus $4\frac{1}{2}$ feet; but this rate of progress could be, and was, increased on emergency, especially towards the end of the work, when the operations were reduced to a regular system.

One of the principal advantages of this system of cylinder sinking is that the rate (and the expense also) of the excavation does not increase with the depth; the quantity of stuff excavated depends upon the power applied to drive the plough and the volume of water flowing up the pipe, and is quite independent of the depth.

The hole excavated was only 9 feet in diameter, but the bottom of the cylinder was 14 feet in diameter, so that a wall of earth $2\frac{1}{2}$ feet in thickness was left all round inside the cylinder. In soft ground the weight of the cylinder was generally sufficient to break this in, but in hard clay it was frequently necessary to weight the cylinder to force it down. Also, when the cylinders were very deep in the ground, they became earth-bound and required weight to force them down.

In the original design, moveable extenders were provided for making the boring-head cut a hole nearly of the diameter of the cylinder, but these were not used, as the arrangement for working them would have been very complicated; and, moreover, it is doubtful whether any advantage would have been derived from

their using, as it would have required more power to drive them than was provided. In practice, the strength of the spur-wheel at the top of the boring-shaft limited the power that could be applied. Being originally of cast iron, the teeth gave way, and it was found necessary to strengthen it by wrought-iron plates, bolted to the top and bottom of the spur-wheel, with teeth cut in them corresponding to the teeth of the spur-wheel.

The hard clay previously referred to required great power to cut it. The slices cut by the ploughs passed up the shaft, and were discharged by the syphon pipe unbroken, although they must have been subject to great attrition in the passage.

The excess pressure of water in the cylinder, acting on the under-side of the cone, reduced the effective weight of the cylinder during boring, and in porous soil tended to prevent the sides of the excavation from falling in, owing to which causes the cylinder seldom went down during the boring.

The ordinary mode of working was to bore down from 1 foot to 10 feet below the bottom of the cylinder, according to the nature of the soil, lift up the boring-head to prevent it from getting buried by earth falling in upon it: then, by stopping the supply of water, the water level in the cylinder was quickly equalized with that in the river by the syphon, and after hanging a few minutes, the cylinder generally went down several feet, until the hole excavated was filled up by the sides falling in. Boring was then resumed, the loose earth which had fallen in was easily removed, and a sufficient depth of solid earth excavated to insure another "run" of the cylinder. Sometimes a slight fall of earth during boring had the effect of partially choking the boring shaft and checking the flow of water out of the cylinder. This was always indicated by the rapid rising of the water in the cylinder. All that was necessary in this case was to lift the boring-head a little, until the syphon began to lower the water level, and then to lower it again rapidly, so as to take advantage of the extra head of water to clean out all the loose earth.

Occasionally, through the carelessness of workmen, galvanized iron buckets, or cane baskets with bolts and nuts, and other articles, were dropped into the cylinder. These sometimes temporarily obstructed the boring shaft, but being twisted and doubled up by the boring-head were always eventually discharged by the syphon. On one occasion a long piece of thick rope got twisted up into a knot by the boring-head and sucked into the pipe, which it effectually plugged, and it was necessary to sight the boring-head before it could be removed.

Land Cylinders.

Each of the land cylinders had to be sunk through about 120 feet of earth. These cylinders were pitched in the dry season and sunk about 40 feet by open excavation, at which depth the pumps were unable to contend with the water rising up into the cylinders. It then became necessary to continue the sinking by boring, and the same principle as had been used in the river cylinders was adopted, with some modifications on account of the altered conditions. (Plate 9.)

The side cutting from which the earthwork of the embanked approach to the bridge was made afforded a considerable reservoir of water, which was used for boring in the dry season instead of the river water, the level of which was too low.

A conduit led the water to a well, or sump, from which it was raised by two 13-inch centrifugal pumps, driven by two 10 H.P. portable engines, into a tank 30 feet high. From this tank the water was led by a horizontal pipe to the cylinder, into which it flowed through a turbine, or horizontal water wheel, by which the boring gear was driven, instead of by a compressed air engine as in the river boring. The water then descended to the bottom of the cylinder and up the boring shaft, carrying with it the earth excavated, and was discharged by a bent pipe, the inner leg of which was immersed in the boring shaft, while the horizontal part passed through a hole in one of the segments of the top ring of the cylinder. To establish the current of water, it was only necessary to fill the cylinder above the level of the horizontal part of the discharge pipe. The earth or sand excavated was deposited in a channel, by which the water flowed back to the reservoir. This channel was cleaned out after each day's boring. It will be seen that this process was more simple than that adopted for sinking the cylinders in the river, inasmuch as by the substitution of the turbine for the compressed air engine, the operations both of driving the boring gear and of removing the earth excavated were performed by the agency of the water only. The water lost by evaporation from the surface of the reservoir during the dry and hot season, and by percolation through the bottom of the cylinder (which was considerable when the cylinder got through the clay into the sand), was replenished by pumping water from the river into the reservoir.

The turbine (Plate 9) for driving the boring gear was of simple construction, being nothing more than a two-bladed screw with a diameter of 16 inches and a pitch of 9 inches.

The quantity of water thrown by the two centrifugal pumps was about 6 cubic feet per second in the 13-inch boring shaft, but the head of water in the cylinder was constantly varying, adjusting itself to the obstruction to be removed. A little practice enabled the assistant in charge of the boring to understand, by the rising or falling of the water, what was going on below. A sudden rise of the water indicated that the boring shaft was closed, by a partial collapse of the sides of the excavation, and that the cylinder was inclined to "run." It was then advisable, after clearing out the loose earth, to lift the boring-head and stop the water supply until the cylinder went down.

Generally when the cylinder was deep in the ground, and therefore a good deal earth-bound, it was necessary to load it with rails and fish-plates to force it down. As this load had to be removed each time the cylinder was lengthened it caused great delay. To obviate this a water-tank, 21 feet in diameter by 10 feet deep, weighing 90 tons when full of water, and which could be filled in ten or fifteen minutes by the pumps, was made to fit on to the top of the cylinder. Unfortunately, the first time this was used, the cylinder punched out the bottom, or rather the crown of the tank, and the rush of the escaping water ripped it to pieces. This mishap was entirely due to the bad quality of the angle-iron, which was a fair sample of the bar iron sold in the bazaar in Calcutta, and which, in default of a better material in store, or when there is not time to indent upon England, is often used. Owing to the late stage of the proceedings at which this mishap occurred, the tank was not repaired; but there is no doubt that the facility of rapid weighting, by means of such a tank, is one of the great advantages of sinking cylinders by the agency of water.

In addition to the weighting, if the cylinder did not go down when the water supply was stopped, after excavating some distance below the cutting edge, it was found greatly to assist in starting the cylinder, if the water inside was lowered by pumping water out of the cylinder. The effect was no doubt due to the infiltration of the water from the earth outside the cylinder tending to loosen and break down the sides of the excavation.

Accident to the Cylinders through a Cyclone.

In carrying out works of this magnitude, it could not be expected that all would go smoothly.

The most serious accident that occurred was caused by a cyclone on the 9th and 10th of June, 1869. It so happened that, in order to

save the time of floating them down, the two cylinders of No. 2 pier had been pitched and sunk a few feet by open excavation in the sand-bank, on the west side of the river, where the water is very shallow in the dry season ; and they were erected complete with the interior ring of brickwork up to the top of the cone. In the month of June the water begins to rise slowly, and on the morning of the 9th, the pontoons were being warped across the river, for the purpose of being put in position to sink the two cylinders. The wind was blowing very strong from the east, accompanied by heavy rain, and there was a strong stream in the river, which, together with the wind, brought a dangerous strain on the warps; so much so that to avoid the risk of parting the warp, and being driven on the No. 4 pier, it was necessary to let go the anchors and moor the pontoons securely. In the meantime the wind increased, and veered round to the south-east, heading back the water in the river. This, together with a heavy down-pour of rain, raised the level of the water about 5 feet. The result was that the two cylinders of No. 2 pier, not being sunk deep enough to stand the scour of the increased force of the stream, were undermined, gradually inclined towards the west, and during the night of the 10th, just as the gale abated, toppled over, and by the morning were completely submerged. Such an accident could not have been foreseen, as under ordinary circumstances there would have been time to get the pontoons into position to support the cylinders before any danger could occur.

No time was lost in ascertaining the position of the sunken cylinders, which was found to be across the stream. After some trouble a buoy-line was rove through each of them. The pontoons were then brought over the down-stream cylinder, and two large spars, with two 1½-inch chains lashed to them, were passed through the cylinder. (Plate 9.) Four five-fold 1-inch chain tackles were then rove from the travelling cranes, and an attempt was made to weigh the cylinder with this purchase; but, although a strain was put on the travellers of about twice as much as they were ever intended to carry, the cylinder could not be removed out of the sand in which it had become buried.

Two more 1¼-inch chains were then rove through the cylinder, and two large pairs of shear legs erected on the pontoons, from which two additional chain tackles were rove and made fast to the chains through the cylinder ; these additional tackles were each hauled on by luff tackles, with six parts of 6-inch Manilla rope in each, and finally the fall or hauling part was taken to the capstan, manned by thirty-six men. With these combined purchases the

cylinder was, after a severe pull, broken out of the sand. The weight of the cylinder itself in water was about 100 tons; but it was much buried in sand, and had, when first broken out, 50 tons of sand inside of it, so that the displacement of the pontoons due to the weight of the cylinder, and including a certain amount of water ballast in the outside compartments, considerably exceeded 200 tons. After much care and trouble the cylinder was lifted out of the water on to the intermediate platform between the pontoons; the brickwork, which had set so hard that it had to be cut out with steel wedges, was removed; and the cylinder disconnected and sent ashore.

Upon returning with the pontoons to pick up the second cylinder, it was found to be almost buried in the sand; and, the buoy-rope being rotten, broke in attempting to haul a chain through the cylinder. All attempts to reeve another rope were unsuccessful, as the cylinder was completely full of sand. The attempt to raise this cylinder was therefore abandoned until the return of the dry season, when, it was hoped, the water being low, there would be a more favourable opportunity of getting at the cylinder. As soon as the water went down sufficiently, a search was made for the sunken cylinder. A complete set of about sixty borings, averaging 70 feet deep, were taken at the place where the cylinder fell over, but no trace of it could then, nor at any other time subsequently, be found. This cylinder, thus completely lost, was 40 feet long, by 14 feet in diameter; weighing, in water, upwards of 100 tons. It is difficult to understand where it can have gone. However, the borings established the fact that the lost cylinder did not, at any rate, obstruct the site of the No. 2 pier; and therefore another cylinder was ultimately procured from England, and sunk in the correct position.

Erection of the Superstructure.

While the cylinders for the piers were being sunk, the main girders for the superstructure had been erected, and rivetted up complete in two parallel rows on the embankment forming the east approach to the bridge; and on the completion of the piers, the launching of the main girders was proceeded with, by means of the arrangements described as follows.

For raising and transporting the girders on land, two powerful lorries were provided. (Plate 10.) The lorries consisted each of two timber side frames in the form of a tetrahedron, their bases being strong sills 18 feet long, shod with two inverted bridge rails, slightly

turned up at the ends, to facilitate their rolling on 3½-inch bar-iron rollers, 10 feet long, laid transversely beneath the girder on an ordinary railway of 7 feet 9 inches gauge, resting on transverse half-sleepers, at intervals of 30 inches from centre to centre. The distance between the centres of the side frames corresponded to the gauge of the railway, so that the 18-feet sills were directly over the rails of the road. The side frames were higher than the girders, and were connected at the top by a 6-inch transverse pin, or axle, passing through the vertical plates of a wrought-iron crown-piece, which formed the top of each of the side frames. Two longitudinal box-girders, 15 feet long, and bolted together at a distance of 2 feet 9 inches from centre to centre, were hung on the transverse axle. The main girders were suspended to the box girders by twenty 1½-inch screw bolts, 8 feet long, ten in each box girder, passing through rivet holes in the top tables of the main girder, which were enlarged to admit the 1½-inch bolts. To lift the girder, the bolts were caused to revolve simultaneously in brass nuts, fixed beneath the top table of the main girder, by means of cranked heads and connecting bars, actuated by worm-wheels and endless screws keyed on a horizontal shaft, which was driven by a power wheel and endless chain. By means of this gearing the girders could be lifted by, and be suspended to the lorries, or, the girder being packed up, the lorries could be lifted on the girder as a fulcrum, the 1½-inch bolts in this case being in compression; this was necessary for the convenience of placing the 3½-inch rollers beneath the lorries.

The lorries were provided with small flanged wheels, which were useful for moving them quickly when they had their own weight only to carry; but when loaded with the main girders they were always moved upon the bar-iron rollers. The rollers were laid at intervals of about 18 inches apart, and by placing them in an oblique direction the girder could be traversed sideways; or by setting them slightly radiating, it could be worked round a curve.

The girders were built upon camber-blocks, or wedges, and were supported by props on either side. One lorrie was attached to the east, or after end of the main girder, and the other to a point about 40 feet from the forward, or west end of the main girder. It was first necessary to raise the girder from the camber-blocks to a sufficient height to allow the bar-iron rollers to pass beneath it. The girder being then packed up to this level, the lorries were lifted and the rollers inserted at intervals of 18 inches. Eighty rollers were provided altogether; twelve were placed under each lorrie,

twelve in position for feeding the after lorrie, and the remainder for feeding the forward lorrie. The lorries being then lowered on to the rollers, the girder was lifted until it was suspended between the two lorries, quite clear of all other support. When the girder was thus weighed, the after lorrie carried 30 tons', and the forward lorrie 75 tons' weight.

To move the girder forward required one hundred Coolies hauling on a 4-inch rope tackle, by which power it was easily moved, notwithstanding the road, owing to the heavy rain that prevailed at the time of launching, was generally in very bad order. As the end of the embankment adjoining the No. 8 pier was newly made, and quite unfit to carry the weight of the girders, a temporary viaduct of 24-feet girders, resting upon brick piers, was formed in the embankment.

The opening between Nos. 7 and 8 piers being mostly over dry ground, a temporary staging, composed of sleepers, flooring girders, and the 46-feet girders of the approach viaduct, was built up to carry the girders across this opening. The roadway over this staging consisted of bridge-rails laid on longitudinal baulks of timber. The staging had to be carefully constructed, as it was necessary that every part of it should be strong enough to support the weight of the west end of the girder, which, including the lorrie, rollers, &c., amounted to 90 tons, on a base of 18 feet.

On the 1st of September, 1870, by means of these appliances, the first girder of No. 7 span was launched forward until the west end was over the cross girders of No. 7 pier, and the east end over the No. 8 pier. The cross girders had been prepared for traversing the main girders laterally, by laying two parallel bridge-rails on packings, by which the upper surfaces of the rails were made level with the cast-iron bearing-blocks on which the sole plates of the girders finally rest. The upper surfaces of these rails were planed, to afford sufficient bearing surface, and to prevent the expulsion of the grease used to diminish friction.

Before the main girder could be lowered on to the sliding rails, it was necessary to remove the rollers from beneath it. For this purpose the girder was lowered on to packing-blocks, the lorries lifted, and the rollers removed from beneath them; the lorries were then lowered on the road, the main girders lifted, the packing-blocks removed, and, finally, the girder lowered on to the sliding rails, and the lorries disconnected and rolled away on the flanged wheels. After the removal of the lorries, the main girder was pushed sideways upon the sliding rails, until it rested in its final position upon the cast-iron bearing-blocks. The second girder

of No. 7 span was launched, and fixed in position in the same way. The flooring girders were then fixed in place, and the railway laid in at the 7 feet 9 inches gauge, ready for the girders of No. 6 span.

The roadway for launching the main girders of the No. 7 span was laid at a level as low as possible, to facilitate the construction of the temporary viaduct, and for other reasons. The No. 7 span having been completed, and the railway laid in at its proper level on the top of the flooring girders, the level of the rails upon the embankment adjoining the bridge required to be lifted 2 feet 9 inches. This was done entirely with broken bricks, to obviate the inconvenience of settlement.

River Launching.

The main girders of the six remaining spans had to be launched over water where no staging could be erected. In this case the principle adopted was to float the forward end of the girders upon a pontoon prepared for the purpose, and to carry the after end on one of the lorries.

In carrying out this system, provision had to be made for constant variation of the water level, the minimum height from the water to the bottom of the girder to be floated being 22 feet, and the maximum height 45 feet. It was also necessary to warp the pontoon across in a straight line, subject to a strong stream, and to the effect of the wind on the area of the girder, 2,400 superficial feet. It was further required to include the means of lowering the forward end of the girder on to the pier after it had been floated across.

With respect to the after end of the girder, it was necessary to outrig the road 15 feet beyond the centre of the pier; because the centre of the lorrie being 6 feet from the end of the girder, the forward end of the lorrie was consequently 15 feet from the end of the girder. The corbelling girders or cantilevers were two box girders, 24 feet long by 21 inches deep by 30 inches wide, resting upon blockings upon the main cross girders of the pier, and prevented from canting by being bolted down at their inner ends to an inverted flooring girder bolted across the bottom of the two main girders of the finished span.

The sole-plate of the girder, as suspended in the lorries during the process of moving forward over the completed span, was about 4 feet above its final level when resting upon the cast-iron bearing-

blocks; and it was therefore necessary to make the screw-bolts of the lorrie long enough to admit of lowering to this extent.

To facilitate lowering the girder, the corbelling girders were made wide enough each to take two parallel rails 18 inches apart, instead of a single rail in the centre of each girder; and about 30 feet of the road near the end of the finished span was also laid with double rails. The object of this was to enable the 10-feet rollers passing beneath the main girders to be replaced by two sets of short rollers about 32 inches long, leaving a gap in the centre, through which the girder could be lowered on to the sliding rails.

The simplest means of lowering the forward end of the girder would have been by sinking the pontoon by admitting water; but no pontoon of sufficient depth of hold for this purpose was available. The most suitable vessel was the iron flat 'Goomtee,' 125 feet long by 25 feet beam by 6 feet depth of hold, drawing about 3 feet of water when loaded with the forward end of the girder. It was therefore unsafe to sink her much more than 12 inches lower in the water in mid-channel, where the stream was very strong.

As before stated, the forward or west lorrie was attached to a point about 40 feet from the end of the girder. Therefore, when the girder was moved forward, so that the west lorrie rested upon the short rollers, with its centre 1 foot beyond the ends of the main girders of the finished span, its forward end projected beyond or overhung the centre of the pier 41 feet. The west end of the girder was then lowered by means of the lorrie gear, until it rested on a wooden packing laid on the cross girder of the pier, at such a level that the bottom table of the girder was about 1 inch clear of the last ordinary flooring girder. By this means the sole-plate at the west end of the girder was lowered to such an extent, that when the girder was floated over, the amount of lowering to be done by sinking the pontoon never exceeded 12 inches.

The girders being only $\frac{1}{60}$ of their length in breadth, when standing singly upon the piers, would have been deficient in lateral stiffness, and, in case of a strong gale acting on the broadside of a girder, it would have been liable to yield by buckling sideways. As a precaution against this contingency, it was necessary to truss the top table of the girders horizontally by cross-trees and chain stays. The trussing was kept on the girders until the support derived from connecting them by the platform girders rendered it superfluous.

In supporting the weight of the girder upon the pontoon, about 65 tons, it was necessary to distribute it over a sufficient length of the vessel, to obviate the danger of breaking her back, and insure

the stability necessary to carry the mass at a height of at least 30 feet above the water. For the former purpose the pontoon was strengthened by a main sill 60 feet long, carried at a height of 3 feet above the deck, by raking shores resting on the "sisters keelsons," and bolted down to the fore and aft central bulkhead by strap-bolts, and terminating at each end with inclined struts for distributing the bearing well forward and aft. Thus trussed, the pontoon, when loaded with 70 tons at the centre, only deflected $1\frac{1}{4}$ inch.

To transmit the weight of the girder to the main sill, a strong pair of shears, or, more correctly speaking, inclined props, were provided, their upper ends clipping the girder beneath the top table, and their heels resting on the main sill of the pontoon, which was moored transversely to the girder.

To prevent undue strain upon the top table of the girder, the point where the weight was supported by the shears was temporarily strengthened, by two flooring girders being lashed on to the top of the main girder, by chains passing round its top and bottom tables, and tightened by wedges of hard wood. It was convenient to keep the inclination of the shears constant, in order that their upper ends might be cut exactly to fit the angle formed by the vertical web and top table of the main girder, and their heels cut to the right level for butting truly on the main sill.

A longitudinal T-iron, screwed on to the centre of the upper surface of the sill, fitted a groove in the heel of the shears, and prevented them from slipping off the sill.

The period at which the girders were launched was the season of the falling of the water in the river, the subsidence of the water level being at the rate of 6 or 8 inches per diem. To meet this condition the shears were so devised as to admit of being lengthened in proportion to the lowering of the water-level. This was effected by building the shears each of four timbers, viz., top and bottom central baulks, connected by hard wood joggles and clamps to two intermediate outside pieces. The timbers were notched at the sides in such a manner that, by loosening the clamps and shifting the joggles, the shears could be adjusted approximately to any required length, and the clamps being then bolted tight again, the shears were hoisted up into position by means of tackles suspended to a kind of framing or gallows erected on the main girder. The shears supported the girder at the point about 20 feet from the end, thus leaving about $7\frac{1}{2}$ feet overhanging the side of the pontoon for landing on the pier.

By means of the shears resting on the main sill, the weight of

the girder was distributed over the pontoon; and the lateral stability of the girders was secured by the longitudinal stability of the pontoon.

To keep the shears upright, that is, to retain the heel of the shears in the same vertical plane as their upper ends, the main sill of the pontoon was connected by chain-stays with the bottom table of the girder at points about 18 feet on either side of the shears, the chains thus forming, with the bottom of the main girder as a base, an inverted triangle having the main sill for its apex. The chain stays were adjusted and tightened up by coupling screws. By this arrangement it was impossible for the pontoon to escape from its load, excepting by the breaking of the chain stays.

The girder being thus balanced upon the pontoon, it was essential to keep the latter as nearly as possible at right angles with the girder during the process of floating it across from pier to pier. This was effected by employing two parallel lines to pay out with, one fast to each cylinder (a distance of 37 feet 6 inches from centre to centre), both lines being paid out simultaneously from a single bollard; and similarly by using two parallel hauling lines, both wound on the barrel of the same winch, so that both lines were equally hauled upon. The winch was placed in a barge secured to the off or west side of the pier on which the girder was to be landed. By these lines the pontoon was kept very nearly at right angles to the girder.

To avoid straining the girder or after lorrie, which admitted of no horizontal swivelling motion, it was necessary that the pontoon should be moved across from pier to pier in a straight line. To facilitate this object, two barges were moored in the line of the centre of the span, the one at a distance of 40 fathoms above the bridge, and the other at a corresponding distance below the bridge. Warps 7 inches in diameter made fast to these barges were led to capstans on the bow and stern of the pontoon. Auxiliary warps were also laid between the barges and pontoons, adjusted by luff-tackles. By heaving uniformly on these warps until the pontoon reached the middle of the span, and then by slacking out, the motion of the pontoon was confined to a straight line within a very few inches. The auxiliary warps were used in case of any sudden alteration in the direction or strength of the wind during the process of launching, which acting on the area of the girder might have brought too much strain upon the single warp.

With these appliances the programme for launching a girder was as follows, viz.:

1st. Lay in the road one rail on each side of the girder, at the gauge of 7 feet 9 inches.

2nd. Run the after lorrie back on the flanged wheels, and tackle on to the after end of the girder.

3rd. Run the forward lorrie back on the flanged wheels, and tackle on to the girder 40 feet from the forward end.

4th. Raise the lorries, block them up 5 inches above the road, and take out the flanged wheels.

5th. By the lorrie-gear lift the girder high enough to get the 10-feet rollers beneath it, with a margin of 3 inches to spare.

6th. Pack the girder up, and lower the girder on to the packing, which may be expected to settle an inch or two.

7th. Lift the lorries by reversing the gear; remove the blockings, and insert the 10-feet rollers at intervals of 18 inches beneath the lorries, and lower the lorries on to the rollers.

8th. Lift the girder, remove the packings, and place the remaining rollers in position for feeding the lorries.

9th. By means of tackle, haul the girder ahead, until all the rollers are exhausted.

10th. Carry the rollers forward; place them ready for feeding the lorries, and haul away again.

11th. Repeat this operation until the forward lorrie arrives at that part of the finished span where the road is laid with double rails for the short rollers.

12th. Place the short rollers ready for feeding the forward lorrie, and haul away until the centre of the forward lorrie is 1 foot beyond the ends of the girders of the finished span; by which time all the long rollers will have run out from beneath the lorrie.

13th. By means of lorrie-gear, lower the forward part of the girder on to the packing of the main cross-girder of the pier.

14th. Lower the after end of the girder on to blocks bearing on three flooring-girders.

15th. Disconnect the after lorrie, and run it back clear of the girder.

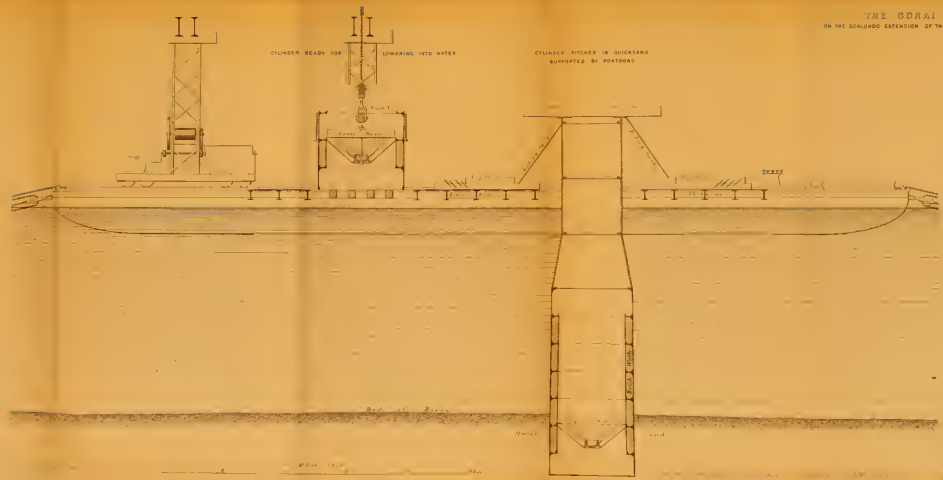
16th. Disconnect the forward lorrie; run it back on the flanged wheels, and fix it on to the after end of the girder, with the rollers beneath it, in lieu of the after lorrie.

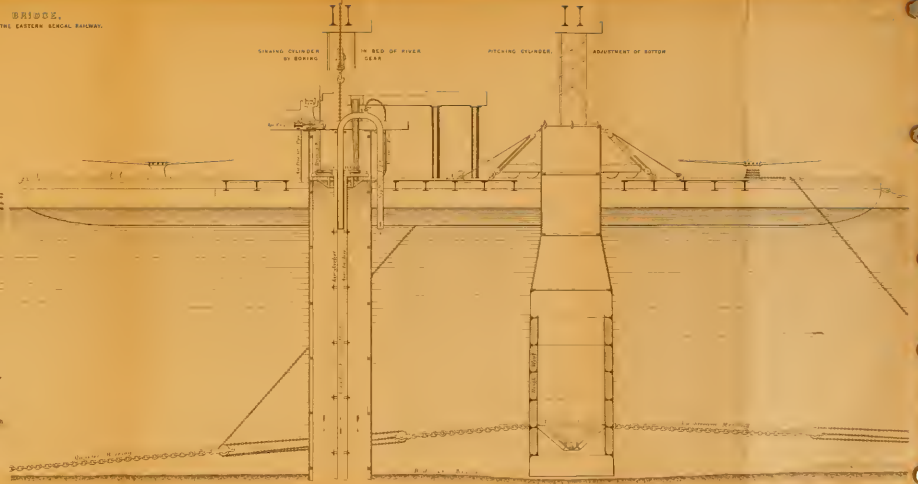
17th. Secure the forward part of the girder by means of inclined struts at the end of the finished span.

18th. Moor the pontoon in position beneath the overhanging end of the girder; pump water in until it is depressed 12 inches, which is the amount of immersion equal to the weight of the forward end of the girder.

THE GORAI BRIDGE.

ON THE GOALUNDO EXTENSION OF THE EASTERN BENGAL RAILWAY.

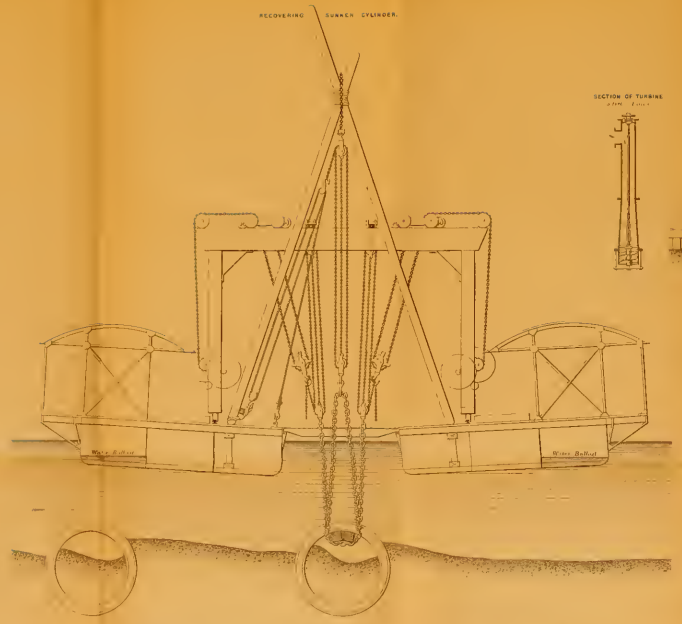




THE GORAI BRIDGE,

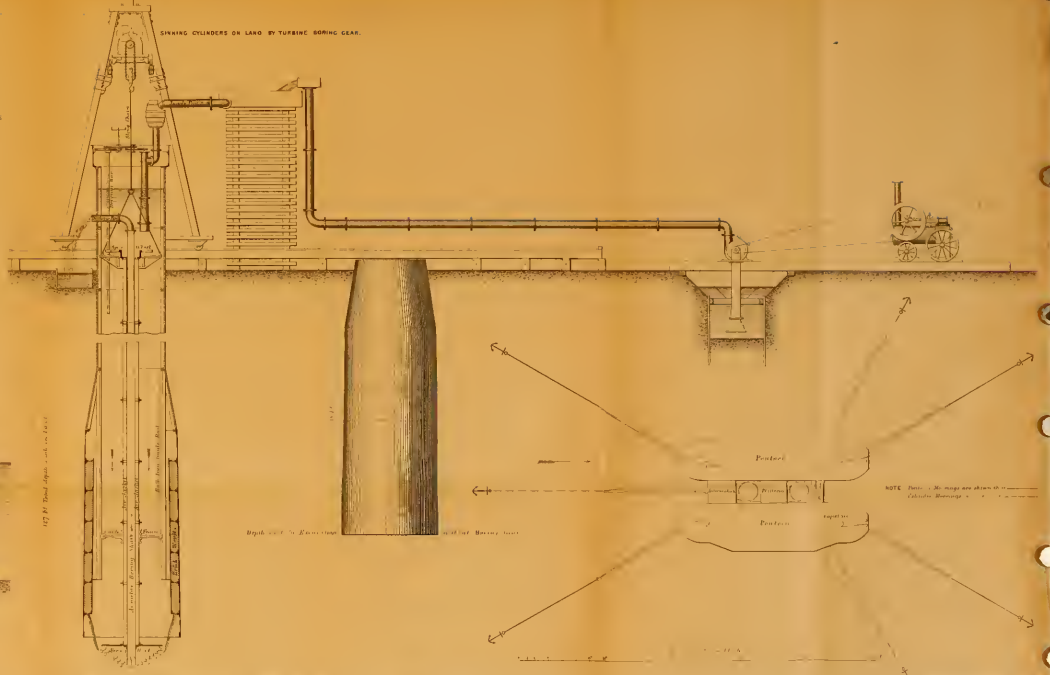
ON THE GOALUNDO EXTENSION OF THE EASTERN BENGAL RAILWAY

RECOVERING SUNKEN CYLINDER.



SECTION OF TURBINE

SINKING CYLINDERS ON LAND BY TURBINE BORING GEAR.

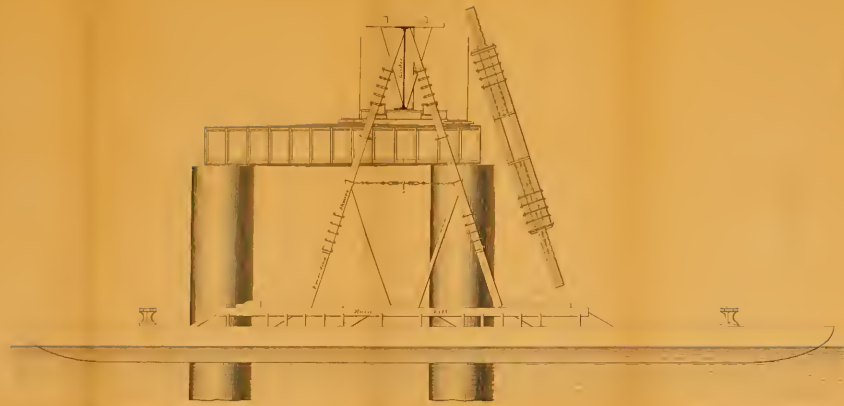


THE SONAI BRIDGE.

ON THE GOALPARA EXTENSION OF THE EASTERN BENGAL RAILWAY

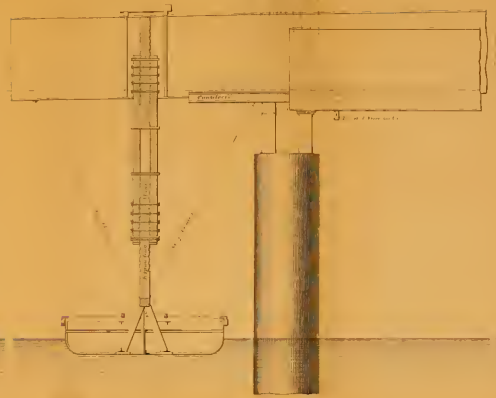
PLATE I

ELEVATION OF PONTOON USED FOR LAUNCHING MAIN GIRDERS



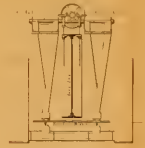
POSITION OF FORWARD LORRIE WHEN MOVING GIRDLE ON FIXED ROAD

LAUNCHING MAIN GIRDERS.



AFTER LORRIE

END ELEVATION OF LORRIE



19th. By tackle from gallows, hoist up the shears until the upper ends are close under the top table of the girder.

20th. Adjust the length of the shears by means of the clamps and joggles, and secure the heels of the shears by the dog-shores.

21st. Make fast the chain-stays, and set them taut by the coupling-screws, so as to adjust the shears in a truly vertical plane.

22nd. Pump the water out of the pontoon, until it lifts the girder off the packing on the cross-girder of the pier.

23rd. By the lorrie-gear, lift the after end of the girder, and remove the blocks.

24th. Lay all the rollers, both long and short, ready for feeding the lorrie, and attach tackles to the after end of the girder for assisting to haul out.

25th. Remove all struts and shores from the girder.

26th. Heave away on the hauling-out lines and tackles; regulate the speed of the girder by the paying-out lines, and keep the girder in line by the up and down stream warps.

27th. Continue heaving until the forward end of the girder begins to overlap the pier; then stop heaving, and ascertain exactly how much farther the girder has to go.

28th. Fix wedges to the rails on the corbelling girders to stop the lorrie, when the girder is far enough, and then heave steady until the girder is brought up by the wedges.

29th. Grease the under-side of the sole-plates of the girder, and sink the pontoon by pumping in water until the forward end of the girder lands upon the sliding-rails on the cross-girder of the pier.

30th. Secure the forward end of the girder by inclined struts and stays.

31st. Continue pumping water into the pontoon until the shears slacken at the top.

32nd. Cast off the chain-stays, and, by means of tackles from the gallows, lower the shears down to the deck of the pontoon.

33rd. By means of lorrie-gear, lower the after end of the girder on to the sliding-rails; disconnect the lorrie, and run it back.

34th. Remove the corbelling-girders from the pier at the after end of the girder, and the struts and stays from the forward end of the girder; and, by means of hydraulic jacks, push both ends of the girder laterally on to the cast-iron bearing-blocks.

The communication is accompanied by a series of diagrams, from which Plates 8, 9, and 10 have been compiled.

Mr. Leslie

Mr. Leslie stated that the first cylinder was put into the water in November, 1867, and the bridge was opened for traffic at the end of 1870. The average time of launching the girders across was one hour, and the whole of the superstructure of the seven spans was erected in seven weeks and three days.

Mr. Redman said this was essentially a Paper upon cylinder foundations, a subject in which he took great interest. When it was considered how great a revolution had taken place in the construction of the foundations of civil engineering works by the introduction of cylinders for such purposes, the small amount of information on the subject in the records of the Institution was surprising. By means of cylinder foundations, the greatest amount of resistance was obtained to the insistent load, with the minimum obstruction to the course of the river.

It had been advanced in a Paper recently read before the Institute of British Architects, on the "Bridges of London," that cylinders were more adapted to railway than road purposes; the objection being urged that in road bridges the strains were more diverse. A solid stone pier might, however, be built for such bridges from low water upwards, or the cylinders might be carried up to the platform level, with transverse diagonal trussing. Perhaps the remark referred to might have been induced by the fact, that the two cylinder bridges over the Thames, at Charing Cross and at Cannon Street, were for railway purposes; there was, however, Mr. Barlow's suspension bridge at Lambeth.

In the early appliances for bridge-building, the interests of a river were, to a great extent, sacrificed to those for internal communication by road. The present condition of the Tiber at Rome was notoriously a case in point. In the old bridge foundations constructed by the mediæval engineers, the piers, as in the case of old London bridge, were formed upon starlings placed in the river, —constructions quite independent of, and projecting far beyond, the piers up to low water, formed by a mass of piles with sheet piling around, and the interstices filled with rubble, supporting the platform of the pier. Floating caissons were next used, as in the cases of old Blackfriars and Westminster bridges, supported on bearing-piles in the former, and upon a dredged bed in the latter. The piers of Vauxhall bridge were also formed by means of caissons. That plan was improved upon by the introduction of the cofferdam, enclosing an area larger than the pier, the foundations of which might be supported upon piles and enclosed with sheet piles, or be carried down to the solid stratum. But the starling, the caisson, and the cofferdam systems were all open to the same

objection, viz., that the river in deepening tended to undermine the foundation. The cylinder system possessed all the favourable features of its predecessors, and accomplished more effectually all that had hitherto been done with the starling, the caisson, and the cofferdam, with, in the latter case, the accompanying bearing and sheet piles, and timber platform thereon for the pier.

The cylinders for the piers of a bridge might be carried down either with or without compressed air, according to the nature of the strata, and to such a depth as to render them quite independent of any anticipated deepening of the river. The Author had not given the weight per superficial foot upon the area of the foundations. Considering the spans, and the diameter of the cylinders, the weight could not be very excessive; he thought, in round numbers, not more than about 3 tons per superficial foot. The weight per superficial foot in the Charing Cross bridge was estimated, he believed, at 8 tons; but he thought that estimate was excessive. In the case of the Gorai bridge, with cylinders sunk 90 feet below the bed of the river, the weight must be immensely reduced by the frictional skin resistance of the cylinders. His estimate in the case of a cylinder sunk to a depth equal to four times its diameter below the bed of the river was, that the weight upon each superficial foot of the base was reduced 20 or 25 per cent.; so that in the Charing Cross bridge the weight would only be about 6 tons, and not 8 tons, per superficial foot, and the weight in the present case would be correspondingly reduced. To illustrate this, it was only necessary to direct attention to the fact, that in sinking, if a cylinder were allowed to obtain a permanent set, it was started again, at times, with the greatest difficulty; and enormous weights were piled upon it, quite out of proportion to the weight the cylinder would ultimately have to carry, as compared with the area it covered.

He believed that the application of cylinders was to a great extent still in its infancy; and that the system was as applicable to the abutments of bridges as to the piers, and for covering large areas for the foundations of quay walls, warehouses, lock pits, graving docks, and other similar structures, with spaces say equal to their diameter (or in some cases more extended, dependent on the nature of the soil) between them. These intervening areas might then be covered with stone landings, iron plates, or a series of flat groined arches. Up to this time, however, cylinders had only been employed for such purposes on a small scale, the efforts to introduce them having been irregular and intermittent; and

there was no example of a large completed work of the above class in this country, where they had been employed upon a scale sufficiently extended to make their application remunerative. It was with some pride he stated, that he was the first Engineer to make use of cylinders in deep water for structures of this kind; for in the years 1842-44 he employed them in the lower portion of the Thames at Milton, below Gravesend, for the Royal Terrace pier.[1] That structure was the pioneer of the entire system, and the use of cylinders had since largely extended throughout the United Kingdom, its colonies, and Indian empire, as well as on the continent of Europe. In India, however, brick cylinders had been used for the foundations of forts, temples, and other massive structures, on the great alluvial plains, the sand being removed by divers, without any attempt being made to displace the water, or to interfere with the balance of pressure within and without the well, and this coincident with all historic records, as had been described thirty years ago in a Paper presented to the Institution by Colonel Goodwyn;[2] but there was no single existing example of deep-water iron cylinder foundations anterior to that he had mentioned.

Mr. Phipps said, that, although convenience of arrangement was no doubt often of more importance than economy of mechanical power, he still thought it desirable to examine the question, and he had made a calculation of the comparative power required to raise the water passed by the syphon, and to raise the solid material from the inside of the cylinder by Mr. Leslie's system. He had been informed by the Author, that the speed of issue through the syphon pipe, 12 inches in diameter, might be taken at 8 feet per second. This would give a weight of water of 1,384,000 lbs. per hour, and, if raised 12 feet above the level of the water in the river, a height considered necessary to meet practical convenience, would absorb 8·5 H.P. The quantity of clay or sand removed from the bottom of the cylinder was arrived at by taking the area of the cylinder into 1 foot, the distance sunk through in one hour, and then taking the material at double the specific gravity of water. The weight per hour was thus 19,125 lbs., which, raised 94 feet, required 0·9 H.P.

The power required to work the boring-head might be assumed at 4·6 H.P. Thus the total power required would be—

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv. pp. 222–246.

[2] *Vide* Ibid., vol. ii. (1842), pp. 63–65; also Ibid., vol. xvi. p. 455.

	H.P.
To raise the water	8·5
To raise the solid material	0·9
To work the borer	4·6
Total . . .	14·0

He would like to ask the Author, whether the mechanism for giving rotation to the boring-head might not have been worked with less power direct from the steam-engine, instead of by using compressed air for that purpose?

In reference to the method used for placing the girders *in situ*, it was a question whether the plan of doing this by the agency of pontoons was more economical, and freer from contingencies, than the well-known plan of drawing or pushing them over the tops of the piers. No doubt a span of 185 feet was very considerable, and the two girders bolted together at the ends would require to be well trussed. But, still, he thought there would not be much difficulty in using that system, and that, as Engineers generally had more experience of working on dry land than with nautical matters, the system alluded to might possibly be preferable.

Mr. J. W. Barry said, considering the conditions, and recollecting that there was a depth of about 40 feet of water, and from 40 to 58 feet of water-bearing soil, every one must appreciate the great difficulties which had to be overcome. The mode in which the water-pressure was used inside the cylinder, instead of, as usual, having to encounter it outside the cylinder, marked this work as one of great peculiarity. There were two well-known difficulties in sinking cylinders; first, in keeping them upright at starting; and, secondly, in avoiding the blowing-in of the soil in the progress of the cylinders downwards. The latter contingency increased with the depth; as an increasing head of water pressing against the bottom ring of the cylinder was encountered. In this case, by keeping the balance of water inside the cylinder, there was only a constant head of from 4 to 5 feet; consequently the cylinder in going down did not much disturb the strata, and the circumstances were most favourable for the cylinder going down quietly and properly, and reaching the bottom with as little trouble at the last point as when it started. By the use of the syphon, and by pumping in clean water and letting it run out dirty through the syphon, the difficulty that always existed in sand pumps, of the sand or other soil destroying the valves and gear of the pumps, was avoided. Although Mr. Phipps was, no doubt, correct in saying

the amount of water raised bore a large proportion to the amount of soil removed, yet it must be recollected, if this mode had not been adopted, the water that came in at the bottom would have had to be lifted; it was therefore a wise thing to utilise it to carry the mud upwards. He believed this mode of sinking was now being extensively used for the shafts of deep mines, in which the cylinder was sunk without attempting to pump out the water, and the same result was obtained, viz., the non-disturbance of the strata.

He would like to ask whether the soil was uniform all the way down? Because he imagined that boulders or other inequalities would have given rise to considerable difficulties. The apparatus, on the other hand, wherever the soil was uniform, would no doubt work as well as it had been found to do in this case.

The air-jacket round the shaft of the cross head was a very pretty appliance. It furnished a ready means of keeping the pressure on the cross head uniform at any depth, and of increasing it when necessary by letting in the water. The Engineer was thus able to deal with different descriptions of soil as he encountered them.

The method of launching the girders was not quite new; but everything seemed to have been done with extraordinary foresight, and with an anxious desire to meet any eventuality that might arise. The execution of the Gorai bridge was a case in which the Engineer designed and carried out the works himself, employing his own labour and plant, and giving the results of his own practical experience. In England the arrangements of similar details were mostly made by contractors, and the Institution, he was afraid, did not derive as much practical experience from them as could be desired. It was to be wished that, when contractors carried out new arrangements, they would give the Institution the result of their experience in dealing with matters which came under their immediate control.

Mr. Bateman observed that the subject of cylinders as foundations for bridges had only within recent years attracted much attention, and there had been numerous successful applications of them. In former times, many of the great weirs across the river-courses of India were formed by sinking wells, side by side, through the sandy valleys down which the rivers flowed; and in that way weirs were raised which answered perfectly. A few years ago he had to advise the trustees of the Clyde navigation relative to a considerable dock extension in the Clyde at Glasgow, where there was a depth of from 50 to 80 feet of quicksand. No ordinary construction under such circumstances could be attempted; the sand

was of a description that, when water came upon it, it became a quicksand; therefore, anything like a cofferdam to get to the rock, 50 or 60 feet below the surface, was out of the question. It however occurred to him that, by a construction of cylinders tongued and grooved into each other, he would be able to erect the quay wall. He had about 4,000 yards of quay work to construct, of which 400 yards were commenced in August, 1870, as an experiment, and were nearly completed in the autumn of 1871. He ventured to say no other kind of building could have been completed to that extent, and ready for the erection of the buildings upon it, in so short a period. The cylinders employed were 12 feet in diameter, built in a succession of rings of brick and Portland cement; the rings being each 2 feet 6 inches in depth, and 2 feet 3 inches in width of rim, the external diameter being 12 feet. He would mention, as an advantage of cylinder construction, that they were grooved into each other with groove and tongue, perfectly straight and perpendicular. The average depth to which they were sunk was 52 feet 4 inches below the surface. They were intended to go 60 feet deep, being 22 feet below the bottom of the river, which was to be dredged to 20 feet at low water. The whole cost of the construction was between £90 and £100 per lineal yard to the depth sunk. Had the depth been 60 feet, which would have been better, the cost would have reached about £113 per lineal yard. Such a construction could be carried on expeditiously by the experience they had gained, and it formed, in his opinion, a very advantageous application of the cylinder system. The excavation within the cylinder was accomplished by a process different to that described by Mr. Leslie, which, however, had greatly attracted his attention, as being exceedingly ingenious and very effective. The excavation was accomplished by Mr. Milroy's excavator,[1] Each ring of which the cylinder was composed was 9 tons in weight, and these were placed one above another to weight the cylinder and carry it down. When extra weight was required, iron rings 5 inches thick, and of 5 or 6 tons weight, were added. There was no difficulty in executing the work, which had been carried out with great success. One disadvantage of building a continuous wall in that way with only one row of cylinders, where the ground was excessively quick or fluid, was, that if the ground were excavated too low in front, the sand from behind would "blow;" and, therefore, the depth to be dredged must be regulated according to the character of the material behind. A

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 339.

case of this kind had occurred, and it had therefore been determined, in the work still to be done, to alter the construction, and to put down two rows 9 feet in diameter, one behind the other; and by that means it was hoped the recurrence of such an accident would be prevented. It was not his intention, however, on that occasion to describe the Clyde Quay wall cylinders minutely. The difficulty he had to contend with in sinking through sand was comparatively small, contrasted with what it must have been in sinking the large cylinders for the Gorai bridge in such a depth of water, and in a current of 3 miles an hour. The success of cylinder construction in one case had given rise to another, and one hardly knew at present the full extent to which the system was capable of being applied.

Mr. Francis Fox, Associate, described some facts relative to a bridge over the Mississippi river at St. Louis, which he visited in the autumn of 1871. In that bridge there were several points of similarity with the one now under consideration. It was found, from the great scour of the stream, that it would not be safe to build a bridge with foundations of less depth than the bed rock, and at the deepest point this rock was about 100 feet below the ordinary level of the water in the river. During the process of sinking, the depth at one time was increased, owing to a flood, to as much as 111½ feet, which was the greatest depth at which human beings were in this instance at work. The principle upon which most foundations were constructed was, either by excavation or piling, to reach a sufficiently firm stratum upon which to build; but this bridge was similar to those wells in India where the masonry or brickwork was commenced before any excavation had been made. The system on which it was built was the following (Plate 11): A large wrought-iron caisson, or air-chamber, was constructed nearly hexagonal in plan, and which he could not describe better than by comparing it to an inverted Thames barge, provided with two strong transverse bulkheads to give lateral stiffness. This being lowered to the river bed, iron plates were added, of sufficient height to bring it up above the water level; then the water was pumped out, and the building of the masonry was commenced upon the top of the air-chamber. As the weight of the masonry pressed upon the sand in the bed of the river, aided by the excavation carried on by the men at work in the air-chamber, the pier gradually sank into the ground. Access was obtained to the air-chamber through the masonry by means of a well and staircase, with a lift in the centre for bringing the men up from their work. There were six other smaller

shafts in the caisson, for bringing up any material which the sand-pumps could not deal with. He need not say that this mode of sinking was a question involving the most anxious considerations in the first instance; but, when he was at St. Louis, the deepest pier had been successfully completed. Considerable mortality had at first occurred amongst the workmen, from the effects of compressed air, and the best remedies not being thoroughly understood. In the case of the pier in the middle of the river, on which three hundred and fifty men were employed, thirty were seriously injured and twelve died. Careful investigations were instituted; and no expense was spared to thoroughly ascertain the causes of the serious effects produced by working under so severe a pressure; and so satisfactory was the result, that when the next pier, or more properly, the abutment, was sunk, though it went to the same depth, there was only one death, and that was owing to the man's own indiscretion. As the caisson penetrated the bed of the river, great inward pressure was exerted upon its sides, and to equalise this the direction of the sand-pumps was changed, and instead of discharging the material from the air-chamber into the river, it was turned into the space between the masonry and the caisson, thus filling it to the level of the river bed. This was advantageous under one condition of things, but was most disastrous under another. A heavy storm occurred, and the river bed was scoured out to a depth of 55 feet; the caisson not being sufficiently strong to resist the unexpected strain that thus came upon it, gave way, and was destroyed. The men were at work inside at the time of the accident, but all were brought up safely. The water penetrated through the brickwork, but was not able to reach the air-chamber, the various shafts being lined with timber to make them water-tight. As soon as the caisson reached the rock, it was fortunately found to be nearly level; there being only a space of about 10 inches difference, and this space was filled with concrete, as, in the first instance, were the whole of the air-chamber and shafts, though afterwards only an outside walling of concrete was used, and the remainder was filled up with sand. In the next pier, or abutment, the upper part of the caisson was dispensed with, as it was found that the uncertain height of the sand might rupture it; and by lining the staircase shaft and the other shafts with timber, there was no danger of the water getting in.

The bad effects of the compressed air upon the men were mostly felt after ascending the staircase. To obviate this a lift was provided, and it was made compulsory upon the men to be lifted up. The men were only allowed to work two shifts per day of forty-five minutes

each, and were made to lie down in a hospital boat, and given small doses of stimulants, for a short time after leaving off work. It was found that the level of the water was generally 1 foot below the bottom of the caisson, owing probably to the difficulty encountered by the air in escaping through the bed of the river; but by inserting a sand-pump into the sand, and having a powerful jet of water playing by a hose, and stirring the sand about, the excavation was satisfactorily effected. Anything like old barges and old steamers that were met with were cut to pieces and sent up the shafts.

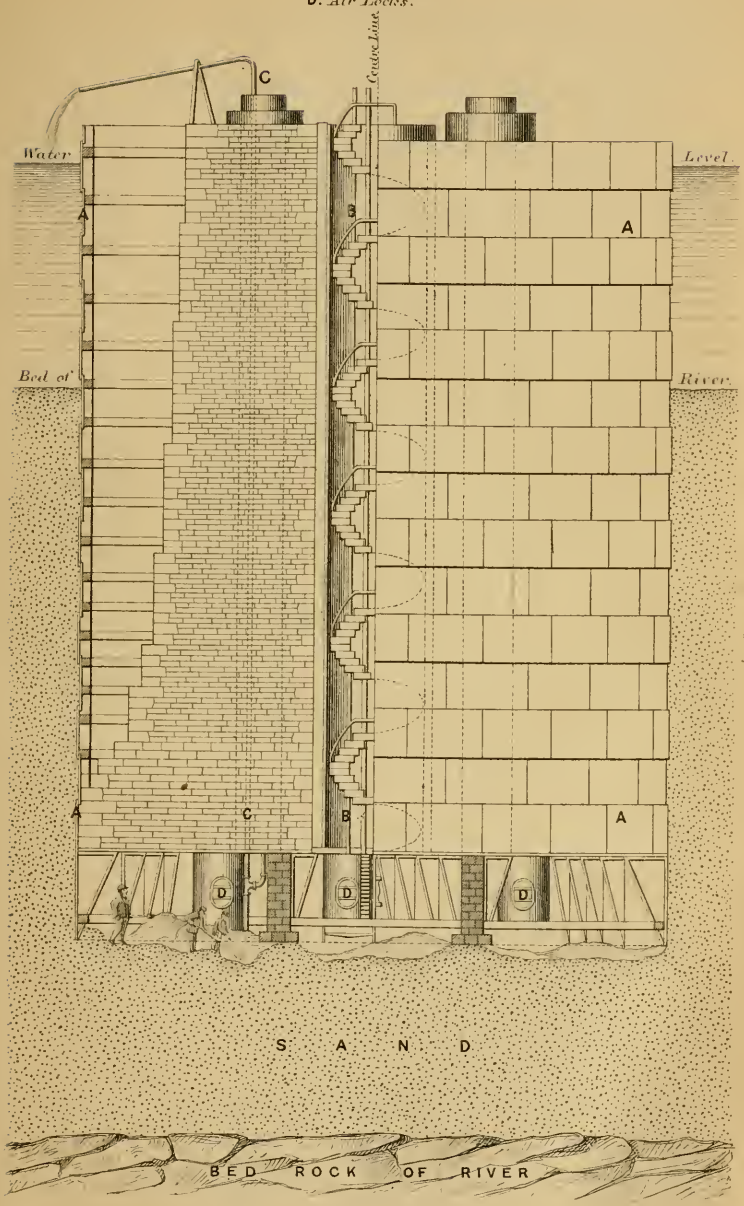
The question of lighting was one of great interest, as it was found almost impossible to blow out a candle in the compressed atmosphere; and on one occasion the clothing of two men took fire and there was great difficulty in extinguishing the flame. It was found that a large quantity of unconsumed carbon from the flames of the candle pervaded the atmosphere of the chamber; and to get over that difficulty, tubes were brought down from the surface, and the candles were burnt in the normal atmosphere in glasses, like those of an ordinary railway carriage lamp, and supplied with air through minute valves from the air-chamber. The interior of the caisson was dry; and to make it as cheerful and comfortable as possible, it was whitewashed and well lighted. A telegraph was in the later operations established between the chamber and the hospital boat and the offices of the company on shore, by means of which constant communication was kept up between them, so that the men had a sense of less isolation than in sinking the previous piers, and greater confidence was thereby inspired. When the air-chamber was at its full depth it was visited by ladies without any ill-effects. The area of the pier was about 5,000 square feet; the total weight of the masonry and superstructure being about 46,000 tons. It was through the kindness of General Eads, M. Inst. C.E., the Chief Engineer, that he was able to communicate these facts. The question of the superstructure was another important matter, which had still to be solved when he was in America. The bridge would consist of three spans of 500 feet each, with arched ribs; but owing to the tornadoes to which that district was subject, the Chief Engineer did not wish to use any staging for the erection of the superstructure; and when he left a plan was under discussion for erecting those gigantic ribs without the aid of staging.

Mr. J. T. Wood thought a few figures, with reference to the commercial aspect of the Gorai bridge, would show that bold works of this kind, looked at in connection with the probabilities of traffic, were neither rash nor unjustifiable. What was looked at in the

ST LOUIS BRIDGE.

PLATE II.

MODE OF SINKING PIER.



F. FOX, DEL.

 BELL BROS. LITH.

first instance was the large produce of the districts east of this railway. It was ascertained that a traffic of about 300,000 tons per annum found its way in native boats to Calcutta. The managers of the railway tried to get a portion of this traffic at Kooshtee, to reach which they had to go 45 miles up stream, which journey occupied a steamer ten hours when the water was low, and twenty hours when it was high. The produce brought down these rivers was principally grain and seeds, the value of which averaged at Calcutta £7 to £10 per ton, and large quantities of jute, the value of which, delivered at Calcutta, was £13 per ton. The estimate made of the cost of loading this produce from railway wagons into boats, and loading again upon the railway, exclusive of the cost of transit, was not less than 1*s.* 6*d.* per ton; while that for carrying the wagons over bodily on a steam ferry brought out a result of about 1*s.* 9*d.* per ton. Taking the average of the traffic at the present moment, the traffic over this bridge was at the rate of not less than 150,000 tons per annum. In the next twelve months it would probably be double that amount. The number of passengers, as calculated from statistics in the preceding half-year, was about 200,000 crossing the bridge. In working out the money results of the present traffic, it appeared that two-thirds of the total receipts were derived from the carriage of goods, and one-third from the carriage of passengers. The cost of this bridge, in round figures, was about £200,000, so that it would require £10,000 a year over the amount of traffic he had mentioned. It worked out, with respect to the 150,000 tons of goods traffic, about 10½*d.* per ton; and in respect of passengers, about 4*d.* each passenger; but it might be preferable to throw the whole charge on the goods, inasmuch as the passenger rate for the third class, of whom the traffic almost entirely consisted, was ⅜*d.* per mile, and a passenger was only charged 1½*d.* for the journey between the two stations adjoining the bridge, including its transit. This would work out at 1*s.* 4*d.* per ton for goods crossing the bridge. This was 2*d.* per ton cheaper than only the loading and unloading as regarded boats, and 5*d.* per ton cheaper than ferrying the loaded wagons across the river. Should however the goods traffic increase to 300,000 tons, the cost of transit would be 8*d.* per ton only. Unless this bridge had been made, not one-third of the traffic which would now obtain over the line could have been acquired. The bridge, therefore, had been a success *per se* in a commercial point of view. He had been acquainted from the beginning with the great difficulties which the Engineers had to encounter, and that, as regarded the transport, the loss of a single vessel might have caused a delay of months. If he

might be permitted to allude to the fact he could not but remember, that this bridge was opened by the nobleman whose premature death they all so greatly lamented. The flattering way in which the Earl of Mayo spoke of the officers by whose skill and energy the work had been completed would long be remembered by them; as also the kindly sympathy expressed by his Lordship with reference to the gloom which had been cast over the Company's officers, on the occasion of the opening, by the sudden death on the previous day, consequent on a lamentable accident, of the traffic superintendent.

Mr. Bruce estimated that the Gorai bridge had cost about £113 per lineal foot, including the land arches. It would add to the interest of the Paper, and enhance its value for future reference, if the Author would furnish the particulars of cost, which he could easily give from the fact of the work having been executed under his own immediate superintendence.

Major J. Browne, R.E., said, the use of cylinder foundations was one of those cases in which modern Engineers prided themselves on adopting a plan which had been applied centuries before. No doubt the arrangement of sinking with syphons was a vast improvement upon the old system of employing divers. Still the principle was essentially one that particularly belonged to India. He could not agree that it was a subject of congratulation that the system had been extended from England to India; indeed he thought it was rather the other way, as the whole of the ancient bridges in India were founded on cylinders, and even in the remote regions of Affghanistan this system was known and practised. In fact, all the bridges over the Thames on iron cylinders were more or less repetitions of what had been done in India for centuries past on the same principle. Cylinder foundations afforded a striking instance of how engineering in one locality acted and reacted upon another locality, to mutual advantage.

With regard to the pressure upon the base of the cylinder, he thought that merely dividing the weight on the cylinder by the area of the base was very misleading. A better estimate of the bearing power of the cylinder might often be obtained, by considering the nature of the strata through which it was driven, and how much friction surface there was below the ground. In illustration, he would mention that in sinking one of the old-fashioned rectangular wells, 18 feet long by 10 feet wide, so common in India, to a depth of 45 feet, where the soil was sandy, at 10 feet from the surface a thin layer of 14 inches of clay was encountered. This, and a depth of 3 feet of sand below was easily pene-

trated. It then came on to rain, and the cylinder stuck fast, and only went down after a great deal of loading. Again it rained, and again the cylinder stuck. It was found that 3 feet of sand had been cleared away under the curb, and that the whole cylinder, weighing 250 tons, was holding on by the friction of the sides alone. The propriety of putting on more weight was being discussed, when a native well-sinker expressed the opinion that by excavating the 10 feet of sand, and cutting away the layer of clay, the cylinder would go down at once, as that layer of clay had swollen during the rain, and held the cylinder just as a shrunk tire held a wheel. Men were set to cut down to the clay; and the moment it was perforated, the cylinder dropped down, which showed that the whole weight was hanging on this 14-inch layer of clay, giving $3\frac{1}{2}$ tons friction per square foot of the layer. Therefore he did not think the estimate of the pressure, obtained by dividing the load by the area of the cylinder, could generally be trusted.

There was a good deal to be said in favour of not employing bolts for fastening iron cylinders together when used below water. About a month ago he saw some bolts that had been brought home from the Bombay and Baroda railway, which had been used under water to fasten the flanges of an iron cylinder, and these bolts were corroded two-thirds of the way through. It would be better to adopt some plan like Westwood and Bailey's slot and stud arrangement, and thus put the pressure on the whole of the thickened end of the flange. There could be no question that the bolts sometimes got corroded, and if they gave way the consequences might be serious.

Though there had been a great many successes, there had also been a great many failures in using cylinders. He had known instances of cylinder-foundations being undermined by the scour of the water, in the Madras and Bombay Presidencies; and last year two accidents occurred from that cause on the Punjab and Delhi railway. In those cases cylinders sunk 45 or 50 feet deep were scoured out; and it ended in an express train falling into 30 feet of water. Where the bed of a river was entirely of sand, there was no reason why, if there was a scour of 50 feet, there should not be a scour of 150 feet. In the northern part of India the floods did not come down once for all, but in a succession of freshets, and these followed so quickly on each other, that before a scour-hole had been filled up with solid sand it was attacked by another freshet. It was in this way the mischief was done, and no one could say where the scour would end. Another difficulty with these cylinders in rivers with sandy beds was that, when the floods

subsided, they left the surface of the sand solid-looking enough, whereas below the surface the scour-hole was filled with light silt which gave way at once in the next flood. The safety of the cylinder seemed therefore to be only a question of how quickly the freshets succeeded each other.

The usual mode of protecting these cylinders was to put in fender cylinders all round them; but this was not the proper principle, for whatever danger the cylinder itself was exposed to was as fatal to the small cylinders sunk round it to guard it. A more effectual protection would be afforded by aprons placed round the cylinder. The chief requirement of such aprons was that they should not be liable to be carried off piecemeal by the river. If made of rigid masonry, the whole apron was likely to fail; whereas an apron if made flexible, and at the same time so connected together as not to be carried away piecemeal, might greatly tend to prevent the scour. He exhibited a small model of a cylinder, showing the manner in which the foundations and abutments in some of the bridges in the Himalayas had been protected. The pier was surrounded by concentric rings of concrete blocks, moulded with a hole through the centre; through this hole a wire cable of three strands of telegraph wire was passed, forming concentric rings, which were again radially connected with each other by means of one single strand of wire. These protecting aprons had been constructed about five years, and it was found that they gave with the stream, bent over where there was danger of scour, and afforded most effectual protection to the foundations. They were quite disconnected from the well, and free to slip down, and so it could be readily ascertained how far the scour had proceeded at the height of any given flood. There was a good deal of economy in using these flexible aprons, inasmuch as when adopted, it was not necessary to sink the wells to the great depth generally given, viz., 70 or 80 feet. Moreover, they were not expensive: protecting a 12-feet cylinder with an 18-feet apron all round would not cost more than £50. In Denmark, and in some parts of Germany, a somewhat similar contrivance was made of fascines, and loaded with stones; and this kind of apron secured the foundations to a great extent. He thought the aprons he had described were worth a trial, particularly as they were not matters of mere theory, but had been found to succeed. It was a most important question to determine what was the best means of founding these great Indian bridges at a small cost; and if these aprons were made sufficiently large, a well might, without danger, be sunk to only a small depth. With sufficiently extended aprons, the scour might

go below the extreme depth of the cylinder without necessarily endangering the safety of the bridge. As a protection to abutments they had been in use since 1867; and during the heavy floods of last year, which were amongst the highest on record, all the abutments which were protected by these aprons stood well, and had not been injured.

Mr. HEMANS, Vice-President, said, it was quite a common practice in the Upper Rhine to protect the feet of retaining walls and the front of piling, liable to the enormous scour of that river, by fascines such as Major Browne had referred to. The fascines were connected by short chains to the piles or upright walls, and were made of very large bundles, often a yard in diameter, well bound together, and loaded with stones. They had the great advantage of following the scour. When the scour occurred under them they subsided to an inclined angle, and when the flood was past they were raised by material put under them. The expense of this plan was moderate, with the great advantage that the apron was self-adjusting.

He considered the decay of the bolts in the flanges of the cylinder, as mentioned by Major Browne, an unimportant circumstance, inasmuch as the cylinders were filled with solid concrete, and they became pillars of rock with a casing of iron, so that the decay of the bolts was of no consequence.

Mr. G. BERKLEY remarked, on the subject of protecting aprons, that there was not much analogy between the Rhine and the rivers of India, where so great a scour as that named in the Paper occurred. He thought Engineers would prefer securing foundations by putting down iron cylinders to a sufficient depth, rather than by masonry aprons.

The system of excavation adopted by Mr. Leslie was not one which could be universally applied in India, for however fair the surface of sand or silt might appear, in some of the Indian rivers boulders were found, and sometimes masses of conglomerate, that could not be excavated in the manner described. Under such circumstances the ingenious system of Mr. Milroy, would also probably fail to do the work. He wished to know whether the cross girders rested upon the cylinders, upon the lining of brickwork, or upon the concrete, or upon all of them, for in a pier of considerable height it was desirable to have but one material on which any great weight should rest.

Mr. REDMAN stated that the purport of his observations had been misconceived. In explanation of his previous remarks, with reference to the extension of the deep-water iron cylinder system

to India, for crossing large, rapid, and deep rivers, he said the observations of Major Browne applied rather to the sinking of brick cylinders on the alluvial plains of India, which was a common mode of construction in that empire for ages past under her Mahometan and Brahminical governors. He submitted that did not at all affect the correctness of his remarks with regard to the extension of the deep-water iron cylinder system to India. The two systems were in effect hardly analogous; the modern system doing what native bigotry considered impossible, viz., bridging the sacred stream.

Mr. Leslie, in reply upon the discussion, said that when the joint at the top of the vertical part of the syphon was well made it held the water for a long time. The syphon frequently remained full all night, and started work in the morning without the necessity of filling it by the vacuum.

As to the disproportion between the power exerted to pump the water and the work done in removing the soil, in the ordinary mode adopted for sinking cylinders, the water must be pumped out. In that case the pumping was for one object only; whereas he removed the soil with the same pumping which would be required to take the water out. There was great waste of power in the pneumatic process, through the air escaping under the bottom of the cylinder, and much more power was required than was represented by the actual amount of work done in lifting the soil. In the case of the Milroy excavator there was also a great waste of power, because the instrument was only employed intermittently; whereas in the plan he adopted the water was continually flowing up the pipe, and the engine was always at work.

The steam-engine in the pontoon was not connected at once to drive the boring gear, as it was an awkward matter to connect a steam-engine afloat at a fixed level with a cylinder which was always going down. If this had been done by belting, it would have got tight or slack as the position of the cylinder altered; therefore it was necessary to have a flexible connection between the power and the object which was moving; and this was done by means of a flexible pipe, which conveyed the air to the air engine. By the other arrangement, used in sinking the land cylinders, the water flowed into the cylinder, and turning the turbine, drove the boring gear, and this mode of transmitting the power from the steam-engine to the boring gear was likewise unaffected by the sinking of the cylinder.

With regard to the launching of the girders, the ordinary plan of connecting two together, and pushing them over rollers upon

the piers, would have brought a greater weight, 220 tons besides the trussing, on a single point than that which he adopted, while it would have been a difficult matter to get rollers that would not have crushed under so great a weight. It would have taken a very large amount of trussing to have held two girders together without straining them; and if two girders of one span had been connected with two of another span, the whole weight of the four girders, with the flooring girders not less than 470 tons besides the trussing, would have required moving upon a single pier; whereas by the plan adopted no great weight was brought upon any point; the greatest weight on one part of the road being 90 tons; and he thought it was safer working afloat than pushing the girders over.

The strata bored through were sand and clay, the latter being of a very dense nature. It was so hard that when the lumps came up they could not be moulded in the hand. The clay was cut by the boring-head into shavings of a curved form. All sorts of things were brought up through the boring-shaft—baskets, buckets, bolts, and tools of every description. These sometimes temporarily obstructed the shaft, and caused an accumulation of water, till there was sufficient head to blow them out. The red lead in the joints used to get squeezed out, and large pieces of that were brought up by the water. It brought up everything which was small enough to go up a pipe 13 inches in diameter. He did not employ the cutter across the bottom of the pipe at first, and in sinking the first cylinders without that cutter large pieces of clay, some of them 12 inches in diameter, and 15 inches long, were cut out like a wad. To break up these wads, which were inconveniently large, he put the cutter across the bottom. From his experience, he should say that the system of excavation adopted at the Gorai Bridge would remove any boulders of moderate size; and when any formation was arrived at so hard that it could not be penetrated by the boring apparatus, he would feel sure that he had met with a good foundation, being quite satisfied that it would resist the scouring force of the heaviest floods.

The decay of the bolts used in fastening the cylinder on the Bombay and Baroda railway was probably promoted by the proximity of the sea, for the water, if not absolutely salt, was brackish, and that acted more rapidly than fresh water; besides, the flanges were outside. But in the cylinders of the Gorai bridge all the bolts were inside, and the joints were caulked, so that there was no flow of water through them. In effect there was no considerable oxidation of the bolts, and he thought they would

last as long as any other part of the work. One of the first cylinders he sank at the Gorai bridge was subjected to a great scour, which went within 18 feet of the bottom of the cylinder, and occasioned him some uneasiness. In order to fill up the hole scoured out, he filled a number of beer-barrels with concrete, chained them together through the bung-holes, and placed them so as to form a complete girdle round the cylinder, which appeared to resemble in some degree the protection Major Browne had referred to. He put down twenty-five to thirty of those concrete barrels in each girdle. They had been there during two rainy seasons, and they filled up the hole that was scoured out, and answered the object perfectly well; by the time the casks decayed the concrete would be solid. This plan was adopted as a quick method of repairing the damage. The barrels were employed to obviate the necessity of using Portland cement for the concrete, which was an expensive material in India, and beer casks were very cheap there. The concrete was made of ordinary hydraulic lime. The girders rested upon cast-iron bed-plates, which were somewhat smaller than the cylinders, the plates resting upon the brickwork. The brickwork was carried to the level of low water in the dry season, and below that the cylinder was filled up with concrete, made of one part of lime, two parts of broken bricks, and one part of unsifted soorkee, or pounded brick, which in India was the substitute for sand in mortar. The concrete used in the cylinders was somewhat expensive, owing to the large proportion of lime put into it. The brickwork of the lining of the cylinders was cheaper than the concrete; otherwise he should have been satisfied to have filled the cylinders with concrete to the top; because, he found from experience in India, concrete was as good as brickwork for such purposes.

One advantage of this system of sinking foundations was the facility it afforded for weighting the cylinders by means of water. The tank for this purpose held 87 tons of water, and weighed 7 tons; it could be placed in position and be filled with water in less than an hour; whereas loading and unloading to the same extent with rails occupied about twenty hours. This means of weighting, however, did not occur to him until he was near the end of the work. From the bad quality of the angle-iron used in the tank, the cylinder punched out the crown of the tank, and the whole contents were discharged upon those who were on the spot, and completely deluged them with water. Being near the end of the work, he did not go to the trouble of having the tank repaired for further use.

In sinking the piers of the St. Louis bridge by the pneumatic process to a depth of 100 feet below the water level, the work was carried on at great risk, and not without considerable loss of life. This justified the rejection of that process for the Gorai bridge, the cylinders of which were sunk to more than 100 feet below the average water level. By the Gorai bridge boring apparatus, the sinking was carried on with the same safety, expedition, and economy, at 120 feet below the water level as it was at a quarter of that depth; and by this process there would be no difficulty in boring to any greater depth that might be required. Another advantage of the system was that, by it, the earth due to the net displacement of the cylinder only was displaced, and the surrounding earth was not in any way weakened or disturbed. The total amount of sinking at the Gorai bridge by the boring apparatus was 1,200 lineal feet. The displacement per foot of cylinder was 5·7 cubic yards, and the cost of sinking, including supervision, labour, fuel, &c., was 4*s.* 6*d.* per cubic yard. By substituting loading by water instead of by rails, and with some other improvements, the cost of sinking could be reduced to 2*s.* 6*d.* per cubic yard.

The total cost of the Gorai bridge had been taken at £200,000; of this sum the pontoons, workshops, and machinery cost £25,000. The pontoons were about to be converted into a floating dock, and the workshops and machinery had been removed and re-erected at the terminus at Goalundo, so that it was but fair to credit the bridge with these amounts, by which the cost was reduced to £175,000. The expenses for inland transport of materials were very heavy. By the company's system, all materials and stores of every description, all workmen and labourers, and even all telegraphic messages carried over the open line for the Extension line, were charged at full tariff rates, which of course swelled the cost of construction considerably. Again, many miles of the line were ballasted with surplus bricks made at the Gorai bridge, the cost of coal and superintendence on which were charged against the bridge. On these and other accounts of a like nature, it was probable that an exact analysis would prove that the actual cost of the bridge did not exceed £165,000.

The cylinders varied from 121 feet to 140 feet in length. The weight per square foot on the base of the long columns, including the moving load, amounted to 8½ tons to the superficial foot. It was not safe to rely on the lateral frictional resistance of the earth on the surface of iron cylinders as a permanent source of support, although it doubtless often exerted a considerable temporary

retarding influence in sinking cylinders. Where the earth was compact and dense it could only exert a small amount of lateral pressure, but where the earth was soft and loose, although it might jam the cylinder for a time, the supporting power of its lateral pressure soon failed, as its cohesion was destroyed by vibration, and the cylinder derived little more support than it would from a fluid. In considering the effect of the pressure of $8\frac{1}{2}$ tons per superficial foot on the foundation of the cylinders, it should be borne in mind, that the normal pressure on the earth at the same level was not less than 4 tons to the superficial foot; and as the foundation was compact sand, it was evident that before the cylinder could sink it must displace the adjacent sand, subject to the pressure of 4 tons, which reduced the effective pressure tending to cause displacement of the foundation to the difference between $8\frac{1}{2}$ and 4 tons, that was to $4\frac{1}{2}$ tons to the superficial foot. For these reasons it appeared that, considering the depth, the weight of $8\frac{1}{2}$ tons to the superficial foot was not excessive; although it would not be safe to load the same description of earth near the surface to the like extent. In point of fact there had been no perceptible settlement of any of the cylinders.

February 20, 1872.

T. HAWKSLEY, President,
in the Chair.

The discussion upon the Paper, No.1,322, "Account of the Bridge over the Gorai River," by Mr. B. Leslie, M. Inst. C.E., was continued throughout the evening.

In pursuance of notice, it was moved, seconded, and resolved unanimously—

"That, in consequence of Tuesday, the 27th of February, having been appointed by Her Majesty 'to proceed to St. Paul's Cathedral to offer thanksgiving for the recovery of his Royal Highness the Prince of Wales,' Hon. M. Inst. C.E., the meeting be adjourned until Tuesday, the 5th of March."

March 5, 1872.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Russel Aitken, Charles Buchanan Ker, and George Thomas Livesey, as Members; Alexander Morton Bell, William Henry Fox, Josiah Harding, Stud. Inst. C.E., *Lieutenant* William Henry Haydon, R.E., *Captain* Robert Francis Taylor, and Hamilton Ela Towle, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VIII., of the Bye-Laws, had transferred Joseph Brierley and William Powell from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—George Edward Abrahams, Roderick William Fraser, Joseph Jones Gardiner, John Prittie Head, James Charles Inglis, Sydney Taber Mowbray, and Charles Reginald Parkes.

No. 1,327.—"On the Kind-Chaudron system of sinking shafts through water-bearing strata, without the use of Pumping Machinery." By Emerson Bainbridge, Assoc. Inst. C.E.

In opening out a new coal-field, in which shafts have to be sunk through measures containing large quantities of water, the cost of the operation constitutes one of the most important items in the total expenditure of capital. The water-bearing strata seldom occur at a greater distance than 200 yards from the surface; and large volumes of water are not generally met below a depth of 150 yards. The thickness of the rocks in which water is found depends upon the porosity and other characteristics of the formations lying nearest to the surface. When the shaft to be sunk exceeds a depth of 200 or 300 yards, the water, if in sufficient quantities to make this necessary, can generally be prevented from interfering with the progress of sinking, by the erection of cylindrical iron tubbing, upon the bed of rock just below the lowest feeder, which rock should be of sufficient compactness to form a barrier against the water. After the water-bearing strata are thus

made secure the lower measures can be passed through as a dry sinking. When the shaft to be sunk has a less depth than 200 or 300 yards the rock is frequently so porous that pumping machinery is required throughout the whole sinking. In this case, the application of tubbing might be temporarily useful, but would soon be rendered futile by the subsidence of the ground, consequent upon the removal of the coal. It happens, however, that shallow sinkings are almost always made through rock of the carboniferous series; and as these rocks are generally of a sufficiently close nature to throw off the surface drainage, it is seldom that excessive quantities of water interfere with the sinkings. An exception to this naturally arises where a recent gravel deposit exists, or where the pit is sunk to the dip of an area to which the drainage of the surface is directed.

Hitherto, the greatest quantity of water has been found in deep sinkings through the upper secondary and the tertiary rocks; the series in which this difficulty has been chiefly met with being the Permian in England, and the chalk in Belgium and France. Sinkings through the Permian rocks have been comparatively rare in England; but where they have been prosecuted the water has been raised by pumping machinery at a large outlay. The recently published Report of the Royal Coal Commission has indicated, that a considerable proportion of the coal, to supply the future manufacturing industry of this country, is only attainable by passing through the Permian rocks, and hence sinkings through water-bearing strata are likely to become much more common. In that Report it is estimated that the quantity of coal remaining in the British Islands is:—

	Million Tons.
Total available coal to the depth of 4,000 feet from the surface .	146,480
Further quantity to the depth of 10,000 feet from the surface .	48,465
	194,945

Of this quantity it is estimated that 104,418 million tons will have to be raised from pits sunk through the Permian and other formations overlying the carboniferous series; so that it may be said that nearly one-half of the remaining deposit of the coal-fields in the British Isles depends upon sinkings where an immense quantity of water may be expected. With such important evidence bearing on the future of coal mining the Author has thought the present an opportune moment, for bringing before the notice of the Institution a system of sinking pits through water-bearing rocks, on a principle, the economical success of

which has been repeatedly proved on the Continent; and to exhibit the results of its application, as compared with the ordinary English system.

In the first place, it may be desirable to describe briefly the system of sinking hitherto pursued in passing through strata yielding large quantities of water. The most important sinkings of this character have been carried out in the county of Durham, to the east of the point at which the Permian overlie the carboniferous rocks. In this district there is a thin bed of sand between the Permian rock and the coal measures. Towards this bed the feeders of water are generally found to increase, and in the sand there is usually a large reservoir of water. The mode of sinking will be understood by reference to Plate 12, Fig. 1. Whilst sinking in hard rock, it has ordinarily been the custom to place iron curbs, or cribs, wherever a bed of stone appeared to form a natural barrier between two distinct feeders of water. Thus it has frequently happened that important feeders have been tubbed back, rendering much less pumping power necessary than would have been required had all the feeders been allowed to accumulate in the shaft. As will be seen by Fig. 1, the number of wedging cribs employed is no less than thirteen in 250 feet. The cribs forming the foundation of each set of tubbing are generally much more massive and costly than the segments of tubbing.

The process of fixing the crib is as follows:—1. The diameter of the shaft is made about 30 inches larger than that of the inside of the 'tubbing.' When a bed of rock, which may be considered sufficiently hard and close to separate the feeders above and below it, is reached, the shaft is contracted to the diameter of the tubbing, and a smooth horizontal face is made on which to place the wedging crib. 2. The wedging crib, which usually consists of segments about 4 feet long by 6 inches high, by 14 inches wide, is placed on the bed. 3. To give the crib a firm and secure position, it is tightly wedged with wood, both behind and between the joints; the tubbing is then built upon it to the next wedging crib, which rests upon a bell-shaped section of rock. 4. When the tubbing nearly reaches this crib, the rock is removed piece by piece, and the top ring of tubbing is placed close up against the crib. It will thus be seen that the fixing of each crib is a costly process, often causing considerable delay.

In some cases, where it has been difficult to find suitable foundations for intermediate wedging cribs, the whole of the water-bearing rocks have been sunk through without attempting to stop

the feeders separately, and no tubbing has been placed in the shaft till the wedging crib could be fixed below the lowest feeder. This process is more expeditious where there are small quantities of water; but where the water is excessive greater delay is caused by contending with it than from putting in numerous sets of tubbing to stop the feeders separately. The tubbing used in England has almost invariably been of cast iron; on the Continent, till recently, tubbing of wood has chiefly been used. Illustrations of both descriptions are shown by Figs. 4 and 5.

Figs. 2 and 3 show, in elevation, the plant and the arrangements generally in use at extensive sinkings. Where the water is in large quantities it is usually pumped by an engine erected for the purpose, assisted by the engine or engines intended to be employed to raise the coal. A small capstan engine is used for passing the men and material up and down the pit during the sinking, such engine being provided also with a drum on slow motion, which is used for heavy weights. The continual pumping, the placing of cribs, and the fixing of the tubbing are proceeded with till the lowest feeder is reached, when a hard bed is sought for on which to fix the lowest wedging crib. In all cases the water has to be pumped out before the wedging crib, which forms the foundation of each set of tubbing, can be placed.

From this description it will be understood that the sinkers (who number from ten to twelve at one time, working four hours at a shift in a pit, say, 14 feet in diameter,) are compelled to work in water until all the tubbing is fixed. This causes a serious obstacle to blasting, and in other ways delays the progress of the work. An opinion may be formed as to the quantity of water which has sometimes to be contended with, and of the power necessary to lift it, by referring to the plant used in sinking a colliery in the county of Durham, where no less than twenty-seven sets of pumps were employed, nine of which delivered the water, amounting at one time to upwards of 9,000 gallons per minute, to the surface. For this, ten pumping engines were used, having an aggregate of 1,584 H.P., and requiring thirty-nine large boilers, which consumed nearly 2,000 tons of coal per week. Seventeen new suction buckets were required every twenty-four hours.

The tubbing used for damming back the water is generally in segments from 1 foot to 3 feet high, and about 4 feet in length, the thickness varying from $\frac{1}{2}$ inch to $3\frac{1}{2}$ inches. It is kept in position by packing with wood behind the joints; and is made water-tight by placing between the segments pieces of wood

sheeting about $\frac{1}{2}$ inch thick, which are wedged when all the tubbing is fixed, usually twice with wood, and sometimes once with iron wedges.

To equalize the pressure of water and gas behind the different sets of tubbing, pass pipes, Figs. 7 and 8 on Plate 12, are sometimes used. Another expedient to effect this is to have a valve, working upwards, placed in the wedging crib, Fig. 6. A ball is also sometimes used, Fig. 9.

This system of sinking shafts through water is that which, until the present day, has been universally followed in this country, and also, with a few exceptions, abroad, where the quantity of water is greater. The evils of the system comprise:—1. The heavy working expenses for fuel, wear and tear of buckets, and powder for blasting; the liability to accidents of a more or less extensive nature to the pumping plant and the original outlay in cases where the winding engines are insufficient to keep the water under. 2. The numerous wedging cribs, and the cost of fixing them. 3. The delay caused by the sinkers being obliged to work constantly in water. 4. The first cost of tubbing, which, being flanged, and in comparatively small pieces, is weak in proportion to its weight, and entails considerable expense in fixing. It is also, owing to the numerous joints, subject to leakage.

The various modes of piercing beds of quicksand constitute a subject so worthy of a separate Paper, that the Author will abstain from referring to this important question further than briefly to enumerate a few of the plans of dealing with strata of this description. They are:—1. By hanging tubbing to that already fixed, and adding fresh rings as the sand is removed. This is only practicable when the quantity of sand is inconsiderable. 2. By heavily weighting a cylinder of iron of the same size as the shaft, and thus forcing it down through the sand. 3. By keeping back the sand by the use of piles—a resource that can only be recommended when the bed of sand is not of great thickness. 4. When the water is excessive, by using pneumatic agency.

M. Levy, of Paris, has kindly allowed the Author to make use of the information furnished by the following table, which presents two important features:—first, the time taken in sinking pits through water-bearing strata, by the ordinary method of raising the water by means of pumping machinery, and shutting off each feeder of water as met with by iron tubbing; and, secondly, the actual cost of sinking per foot. The results will be referred to hereafter.

TABLE I.—Showing the Duration and Cost of Eleven different Sinkings made by the ordinary process (Niveau Vide), the feeders of Water being contended with by Pumps.

Locality.	Name of Colliery.	Year in which Sinking was commenced.	Diameter of Pit when finished.	Depth of Pit to bottom of Water-bearing Strata.	Total Length of Tubbing in the Shaft.	Time.		Pumping.	Cost.	
						Duration of Sinking to the date of the completion of Tubbing.	Average Rate at which Sinking progressed.	Quantity of Water met with and raised.	Of each Pit up to time of completion of Tubbing, including Engines, Pumps, Boilers, and all other Expenses incident to Sinking.	Complete Cost per Foot to bottom of Water-bearing strata in each Pit.
			Feet.	Feet.	Feet.	Months.	Feet per Month.	Gallons per Minute.	£	£
Germany	Carling, Moselle	1858	13·38	524	501	58	9·2	2,310	88,000	168
	Merle Bach	..	13·35	570	484	91	6·2	2,200	140,000	245
	St. Stephanie, 1	1857	13·12	434	364	110	3·9	1,920	96,000	111
	,, ,, 2	1857	13·12	428	358	110	3·9			
	Falck	1859	13·77	239	174	40	5·9	606	37,000	155
France	Marles Pas de Calais	1853	14·76	271	240	39	6·9	121	17,000	63
	St. Pierre, Nord, 1	1864	13·12	550	308	71	17·0	3,300	42,847	36
	,, ,, 2	1864	10·49	656	243					
	Thiers	1856	13·12	213	213	26	8·2	9,900	32,436	152
	L'Escarpelle, 1	1867	13·12	82	..	32	4·6	..	24,000	164
	,, ,, 2	1867	13·12	64	..					
Belgium	Havre, 1	1865	11·81	249	124	52	17·2	2,200	112,000	125
	,, 2	1865	11·81	331	124					
	,, 3	1865	11·81	314	124					
	Malbos Gard	1861	13·12	514	452	91	5·6	616	44,720	87
England	Hetton, 1	..	14·00	540	340	..	..	..	156,000	96
	,, 2	..	14·00	540	340					
	,, 3	..	14·00	540	340					

Having thus drawn attention to the ordinary plan of sinking, a description will now be given of the system which it is the immediate object of this Paper to bring before the Institution.

For many years a mode of boring Artesian wells by a peculiar class of tools (already described by Mr. Burnell in the Minutes of Proceedings[1] of the Institution) has been carried out by Mr. Kind, a German Engineer. A few years ago, M. Chaudron, of Brussels, first attempted to apply this boring apparatus for sinking mines of large diameter, where considerable quantities of water had to be encountered, adding to it a moss box (boîte à mousse) to form a water-tight joint at the base of the tubbing. By this process ten mines have been sunk on the Continent with great success. Two pits at Maurage, near Mons, situate in a district where some of the most costly sinkings in Belgium have been prosecuted, are now being put down. In company with Mr. W. Cochrane, the Author visited these pits in October, 1871, and had the system fully explained by M. Chaudron. A platform or scaffold was fixed at a distance of 10 feet below the surface, on which the sinkers were at work. The water level was reached at a distance of 37 feet from the surface. At the date of the Author's visit the shafts had never been seen below this point, but had been sunk under water, in one pit to a depth of 593 feet, and in the other to a depth of 373 feet. M. Chaudron's system is divisible into the following distinct processes, which it is proposed to refer to in order. 1. The erection of the necessary machinery on the surface, and the opening of the mine. 2. The boring of the pits to the lowest part of the water-bearing strata. 3. The placing of the tubbing. 4. The introduction of cement behind the tubbing to complete its solidity. 5. The extraction of the water from the pits, and the placing of the wedging cribs, or 'faux cuvelage,' below the moss box.

1. *The erection of the machinery and the opening of the Mine.*

Figs. 10, 11, and 12, Plate 12, show in elevations and in plan the plant usually employed on the surface. D is a small capstan engine, having a cylinder 20 inches in diameter and a stroke of 32 inches, working on the third motion. Attached to this engine, and working in the small pit C, is a counterbalance weight. This engine is used for raising and lowering boring tools, and for lifting the debris resulting from the boring. As far as the platform, which is about 10 feet from the surface, the pit has a diameter of 19 feet, or 4 feet more than the diameter of the pit

[1] *Vide* Vol. XXIII. p. 459.

below. At a level of about 38 feet above this platform, there is a tramway on which small wagons run, carrying the debris cylinder on one side, and the boring tools on the other. At a level of 48 feet above the platform are placed supports for the wooden spears to which the boring tools are attached. The machinery for boring is worked by a cylinder, which has a diameter of $39\frac{1}{3}$ inches, and a full stroke of $39\frac{1}{3}$ inches, the usual stroke varying from 2 feet to 3 feet. A massive beam of wood transmits motion from this cylinder to the boring apparatus, the connection between the beam and the piston rod and the beam and the boring tools being made by a chain. The engine-man sits close to the engine, and applies the steam above the piston only. The down stroke of the boring tools is caused by the sudden opening of the exhaust, and a frame then prevents the shock of the boring rods from being too severe. The engines work at speeds varying from 12 to 18 strokes per minute, according to the character of the strata passed through.

2. *The boring of the Pits to the lowest part of the water-bearing strata.*

After the working platform is fixed, the first boring tool applied is the small trepan—Figs. 1, 2, 3, and 4, Plate 13. This tool is attached to the wooden beam by the arrangement shown by Fig. 15. The boring tools can be lowered at pleasure by means of an adjusting screw, which can be moved a distance of 2 feet inches. Next in order comes the handle for boring. This is worked by four men on the platform, and is turned by the aid of a swivel. Attached to the handle-piece are wooden rods, made from Riga pitch pine. These rods are 59 feet in length, and $7\frac{3}{4}$ inches square. A swivelled ring is attached to the rope when raising and lowering the boring rods. The small trepan cuts a hole 4 feet $8\frac{3}{4}$ inches in diameter; and has fourteen teeth, fitted in cylindrical holes, and secured by pins entering through circular slots. The teeth are steeled. At a distance of 4 feet 4 inches above the main teeth of the trepan there is an arm, with a tooth at each end. This piece answers the purpose of a guide, and, at the same time, removes irregularities from the sides of the hole. At a distance of 13 feet 6 inches above the main teeth are the actual guides, consisting of two strong arms of iron fixed on the tool, and placed at right angles to each other. The hole made by the small trepan is not kept at any fixed distance in advance of the full-sized pit, but the distance generally varies from 10 to 30 yards. With the small trepan, which weighs 8 tons, the progress varies from 6 to 10 feet per day.

The large trepan, Figs. 5, 6, and 7, weighs $16\frac{1}{2}$ tons, is forged in one solid piece, and has twenty-eight teeth. A projection of

iron forms the centre of this trepan, and fits loosely into the hole made by the small trepan, acting as a guide for the tool. At a distance of 7 feet 6 inches above the teeth, a guide is sometimes fixed on the frame, but is not furnished with teeth. At a distance of 13 feet 3 inches from the teeth are two other guides at right angles to each other. These guides are let down the pit with the boring tool, the hinged part of the guides being raised whilst passing through the beams at the top of the pit, which are only 6 feet 7 inches apart. When the tool is ready to work, the two arms are let down against the side of the pit, and are hung in the shaft by ropes, thus acting as a guide for the trepan, which moves through them. To provide against a shock to the spears when the trepan strikes the rock at the down stroke, at the upper part of the frame a slot motion is arranged, the play of which amounts to about $\frac{1}{2}$ inch. The teeth of the large trepan are not horizontal, but are deeper towards the inside of the pit, the face of the inside tooth being $3\frac{3}{4}$ inches lower than the outside. The object of this is to cause the debris to drop at once into the small hole, by the face of the rock at the bottom of the pit being somewhat inclined. The teeth used are the same both for the large and the small trepan, and weigh about 72 lbs. each. As a rule, only one set of teeth is kept in use, this set working for twelve hours, the alternate twelve hours being employed in raising the debris. This time is divided in about the following proportions: Boring, twelve hours; drawing the rods, one hour to five hours, according to depth; raising the debris, two hours; and lowering the rods one hour to five hours. The maximum speed of the larger trepan may be taken at about 3 feet per day. The ordinary distance sunk is not more than 2 feet per day, and in flint and other hard rocks the boring has proceeded as slowly as 3 inches per day.

The debris in the small borehole contains pieces of a maximum size of about 8 cubic inches. In the large boring pieces of rock measuring 32 cubic inches have been found. As a rule, however, the material is beaten very fine, having much the appearance of mud or sand. In both the large and the small borings the debris is raised by a sludger or spoon (Figs. 8, 9, and 10), consisting of a wrought-iron cylinder, 3 feet 3 inches in diameter, by 6 feet 9 inches long, and containing two flap valves at the bottom, through which the excavated material enters. This apparatus is passed down the shaft by the bore rods, and it is moved up and down through a distance varying from 6 to 8 inches, for about a quarter of an hour, and is then drawn up and emptied. In some cases where the rock is hard, three sizes of trepan are used consecutively, the sizes being;—5 feet, 8 feet, and 13 feet.

The several other tools and appliances used during the boring operations are shown on Plate 13, including the key used at the surface to disconnect the rods, the hook on which each rod is hung after being raised to the high platform and there detached, the bar upon which the hooks are moved, and the fork for suspending the rods or tools from the little wagons when it is desired to move the rods or tools from above the shaft.

Should broken tools, &c., fall into the shaft, several varieties of apparatus are used for their recovery. In case of broken rods of any kind having a protuberance that can be clutched, a hook of an epicycloidal form enables the object to be taken hold of very readily. Where the broken part has no shoulder which can be held, but is simply a bar, the apparatus shown by Figs. 11 and 12 is employed. This is composed of two parts. The rods M.M, the bottom of which have teeth inside, are prevented from diverging by the cone and slide on the main rods. When passed over a rod or pipe, they clutch it by means of the teeth, and draw it up. M. Chaudron has, by this tool, raised a column of pipes 295 feet in length and 8 inches in diameter. An instrument, called a 'grapin,' Figs. 13 and 14, is used for raising broken teeth or other small objects which may have fallen into the bottom of the shaft. This tool also has one part sliding in the other, and is lowered with the claws closed. The parts B B are moved by two ropes worked from the surface. By weighting the bar A A, which is attached to the moving parts, the pressure desired can be exerted on the claws C C. The weight is then lifted, the claws are opened, and are made to close upon the substance to be raised. This instrument is now seldom required; in the Maurage sinkings it has only been employed once.

It may be remarked that, in the use of all the boring implements to which reference has been made, accidents of any kind are of rare occurrence, the experience already gained offering a sure guide as to the strength of material, &c. In boring shafts in the manner described, without being able to prove in the usual way the perpendicularity of the shaft, it might be feared that the system would be open to objection on this account. It appears, however, that in all cases where M. Chaudron has sunk shafts by this system he has succeeded in making them perfectly vertical. This is insured by two modes:—1. By the natural effect of the treble guide, which the chisels and the two sets of arms attached to the boring tools afford. 2. If the least divergence from a plumb line is made by the boring tool, the friction of the tool upon one side of the shaft is so great as to cause the borers to be unable to turn the instrument.

Boring alternately with the large and the small instrument, the shaft is at length sunk to the point at which the lowest feeder of water is encountered. In a new district this has to be taken, to some extent, at hazard; but where pits have been sunk previously, it is not difficult to tell, by observing the strata, almost the exact point at which the bottom of the tubbing may be safely fixed. This point being ascertained, the third process is arrived at.

3. *The placing of the Tubbing.*

As the object of placing tubbing in a shaft is effectually to shut off the feeders, and to secure a water-tight joint at the base, it is important that the bed on which the moss box has to rest should be quite level and smooth. This is attained by the use of a tool termed a 'scraper,' attached to the bore rods, the blades being made to move round the face of the bed intended for the moss box. The tubbing employed is cast in complete cylinders. At Maurage each ring has an internal diameter of 12 feet, and is 4 feet 9 inches high. Each ring has an inside flange at the top and bottom, and also a rib in the middle, the top and bottom of the ring being turned and faced. The rings of tubbing are attached to each other by twenty-eight bolts 1·1 inch in diameter, passed through holes bored in the flanges. The tubbing is suspended in the pit by means of six rods, which are let down by capstans placed at a distance of 30 feet above the top of the pit. These machines work upon long screws. When a new ring of tubbing is added, the rods are detached at a lower level, and are hung upon chains, thus leaving an open space for passing it forward. Before each ring is put into the pit it is tested by hydraulic apparatus, Fig. 40. The tubbing is usually proved to one-half more pressure than it is expected to be subjected to. At Maurage, where a length of 550 feet of tubbing has to be put in, the chief particulars respecting it are:—

TABLE II.

——	Length.	Thickness.	Pressure expected.	Pressure at which Tubbing is proved.
	Feet.	Inches.	lbs. per sq. Inch.	lbs. per sq. Inch.
Top . .	130	1·17	30	45
	60	1·31	60	90
	60	1·57	90	135
	60	1·76	120	180
	60	1·96	150	225
	60	2·16	180	270
	60	2·35	210	315
Bottom .	60	2·55	240	360

The joints between the rings of tubbing are made with sheet lead $\frac{1}{8}$ of an inch thick, coated with red lead. The lead is allowed to obtrude from the joint $\frac{1}{3}$ of an inch, and is wedged up by a tool which has a face $1\frac{1}{2}$ of an inch thick. The mode of suspending the tubbing to the rods, will be understood by referring to Plate 13. The rods are attached to a ring by the bolts connecting one ring of tubbing with another. The bottom ring of tubbing and the ring carrying the moss box have their top flange turned inwards, but their bottom flange outwards. A strong web of iron, forming the base of a tube $16\frac{1}{2}$ inches in diameter, is attached to the tubbing. The object of this tube is to cause the water in the shaft to ease the suspension-rods, by bearing part of the weight of the tubbing. Cocks to admit water are placed at intervals up the tube, by which means the weight upon the rods can be easily regulated so that not more than one-tenth to one-twentieth of the weight of the tubbing suspended by the rods at one time. The ring holding the moss box is hung from the bottom joint in the tubbing by sliding rods.

The arrangement of the moss box (boîte-à-mousse), which forms the base of the tubbing, is one of the most important points requiring attention in this system of sinking. Ordinary peat moss is used. It is enclosed in a net, which, with the aid of springs, keeps it in its place during the descent of the tubbing. When the moss box, which hangs on short rods fixed to the tubbing, reaches the face of rock, it is dropped gently upon it, and the whole weight of the tubbing is allowed to rest upon the bed. This compresses the moss, the capacity of the chamber holding it is diminished, and the moss is forced against the sides of the shaft, thus forming a water-tight joint, past which no water can escape. This completes the third process.

It may be noted that up to this point the following important differences between this and the ordinary system of placing tubbing are to be observed :— 1. The tubbing, on reaching its bed, bears the aggregate pressure of all the feeders of water which have been met with in the shaft. 2. The tubbing, having been passed down the shaft in the manner described, no wedging behind, or other modes of consolidating it in the shaft, have been carried out. 3. The connection between each ring of tubbing is so carefully made, that the repeated wedging of the joints, as in the ordinary system, is rendered unnecessary. 4. The pit is still full of water up to the ordinary level.

Under these conditions the next process is :—

4. *The introduction of Cement behind the tubbing to complete its solidity.*

Before the water is removed, the annular space between the tubbing and the sides of the shaft is filled with hydraulic cement, to render the tubbing impermeable, by a process of consolidation, less liable to the effect of any pressure of water, or gas, which may be exerted towards the centre of the shaft. The cement is inserted behind the tubbing by close-ladles (Figs. 38 and 39), capable of holding 44 gallons, and consisting of two iron plates, $\frac{1}{8}$ of an inch thick, fixed on two wooden uprights $3\frac{1}{8}$th inches square. This apparatus is curved to suit the mean circumference of the space to be concreted. A piston is placed at the top of the ladle, and to this piston is attached a rod, which can be moved from the surface; a door is also attached to the piston. The ladle containing the concrete is passed down behind the tubbing by means of a windlass at the surface, and when it reaches the lowest point, the piston is pushed down and the cement allowed to escape from the chamber. The weight of the cement and the ladle is sufficient with a little ballast to enable it to descend easily.

A number of experiments have been made to discover a cement which will not harden too quickly, and which, when hardened, will form a perfectly compact and solid mass. A composition having the following proportions, has been found the best:—1. Hydraulic lime, from the lias near Metz, slacked by sprinkling, 1 part. 2. Picked sand, from the Vosges sandstone, 1 part. 3. Trass, from Andernacht on the Rhine, 1 part. 4. Cement, from Ropp (Haute Sâone), $\frac{1}{4}$ part.

Six men are employed in putting in the cement, viz.:—two at the windlass for letting down the ladle, two for working the rods attached to the piston, and two on the working platform. The rods referred to have been found such an inconvenience, that lately a rope on another windlass has been used, and an appliance arranged for dropping the piston by moving the rope.

5. *The extraction of the water from the Pits, and the placing of the wedging cribs, or 'faux-cuvelage' below the moss box.*

When a sufficient time has elapsed for the cement to harden, the water within the tubbing, now effectually separated from the feeders, is drawn out by a bucket worked by the crab engine,—an operation which occupies from one to three weeks, according to circumstances. When concluded, the joint between the moss box and the rock bed can be examined. In some cases this joint is

considered sufficient; but it is generally thought desirable to form a base to the tubbing (Fig. 37), by building a few feet of brickwork in cement on a ring or crib of wood. Another wooden crib is then placed on the top of this brickwork, and above this, two cast-iron segmental wedging cribs with a broad bed also wedged perfectly tight. On the base so prepared, four or more rings of tubbing in segments are fixed, the top ring coming close against the bottom of the moss box. This being done, the work is completed, and the sinking of the shaft is continued in the ordinary way.

The application of the boring trepan is not to be recommended in the sinking of the dry part of the shaft. The use of the tool would cause the sinking to extend over a longer period, since the breaking of the rock passed through into such minute particles would lead to loss of time. In the sinking of shafts by the process described, an observer cannot but be struck with the very small staff of workmen. The number of men employed in a day of twenty-four hours at the two pits at Maurage, when visited by the Author, were:—4 chief sinkers, 16 ordinary sinkers, 4 blacksmiths, 4 strikers, 1 fitter, 4 firemen, 3 labourers, and 4 other hands; making a total of 40; and they worked in shifts of twelve hours, 20 workmen being thus engaged at one time.

The apparatus for lifting and moving heavy tools and material is so perfect, and works so automatically, as to leave little scope for improvement. The proportion of time required for the different processes, and the per centage of the same, for each class of work executed at Maurage, are as follows:—

Time for each Class of Work.	Months.	Percentage.
Erection of surface arrangements	6	18
Boring	18	52
Placing tubbing	3	9
Fixing cement	2	6
Hardening cement	2	6
Raising water, and placing wedging cribs	3	9
	34	100

To compare with the table previously given, the following is intended to show the results, both as to expenditure of capital and time occupied, at the mines where the Kind-Chaudron process has been adopted:—

TABLE III.

SHOWING the DURATION and COST of EIGHT different CONTINENTAL SINKINGS made by the KIND-CHAUDRON process.

Locality.	Name of Colliery.	Year in which Sinking was commenced.	Diameter of Pit when Finished.	Depth of Pit to bottom of Water-bearing Strata.	Total Length of Tubbing in the Shaft.	Time.		Cost.					Total.	Complete Cost per Foot to bottom of Water-bearing Strata in each Pit.
						Duration of Sinking to the date of the completion of Tubbing.	Average Rate at which Sinking progressed.	Surface Plant.	Boring.	Tubbing.	Concrete Work.	Wedging Cribs at Bottom, &c.		
			Feet.	Feet.	Feet.	Months.	Feet per Month.	£.	£.	£.	£.	£.	£.	£.
Belgium	St. Waast	1853	11·90	321	219	26	12·4	1,216	2,048	5,110	Comprised in Cost of 'Tubbing.'		8,374	26
	St. Marie	1859	5·97	344	202	14	24·5	640	750	1,188			2,578	7
	St. Barbe	1862	11·97	295	177	19	15·5	2,916	940	1,224	..	938	6,018	20
France	L'Hôpital, 1	1865	5·90	521	472	43	12·1	1,988	3,720	3,180	472	246	9,606	18
	„ 2	1865	11·15	523	469	39	13·4	2,636	5,670	6,768	600	400	16,074	30
Westphalia	Rothuasen, 1	1866	6·23	331	221	14	23·6	1,852	1,496	2,752	408	280	6,788	20
	„ 2	1866	11·97	341	334	25	13·6	3,186	3,068	5,700	574	600	13,128	38
France	L'Escarpelle, 1	1867	10·49	354	332	11	32·2	1,608	1,108	3,612	363	310	7,001	20
	„ 2	1867	7·21	..	..	..	..	Now being prosecuted.						
Belgium	Maurage	1869	11·97	656	541	..	..							

In order to show a direct comparison between the two systems of sinking shafts, the following extracts from the previous tables are given :—

TABLE IV.—SUMMARY of TABLES I. and III., for comparison of the modes of SINKING.

Ordinary mode of Sinking.						Kind-Chaudron System.					
Nos.	Depth of Pit to bottom of water-bearing strata.	Time.	Feet per Month.	Total Cost.	Cost per Foot.	Nos.	Depth of Pit to bottom of water-bearing Strata.	Time.	Feet per Month.	Total Cost.	Cost per Foot.
	Feet.	Months.		£.	£.		Feet.	Months.		£.	£.
1	524	58	9·2	88,000	168	1	321	26	12·4	8,374	26
2	570	91	6·2	140,000	245	2	344	14	24·5	2,578	7
3	434	110	7·8	96,000	111	3	295	19	15·5	6,018	20
	428					4	521	43	12·1	9,606	18
4	239	40	5·9	37,000	155	5	523	39	13·4	16,074	30
5	271	39	6·9	17,000	63	6	331	14	23·6	6,788	20
6	550	71	17·0	42,847	36	7	341	25	11·6	13,128	38
	656					8	354	11	32·2	7,001	20
7	213	26	8·2	32,436	152						
8	82	32	4·6	24,000	164						
	64										
	249										
9	331	52	17·2	112,000	·125						
	314										
10	514	91	5·6	44,720	87						
Total .	5,439	610	88·6	634,003	1,306		3,030	191	145·3	69,567	179
Average	544	61	8·8	£63,400	£114·6		379	24	18·1	£8,696	£22·4

NOTE.—Hetton statistics are omitted, owing to imperfect information.

Thus on an average of ten sinkings, by the method practised in England, the speed of sinking was equal to 8·8 feet per month, and

the cost was £114·6 per foot; whilst with the Chaudron system the average of eight sinkings shows a cost of £22·4 per foot, the progress made per month amounting to 18·1 feet. This striking result illustrates the great importance which the Kind-Chaudron mode of dealing with water-bearing strata is likely to have. This comparison cannot be considered to apply with all its force to English mining, since, as a rule, the sinkings abroad encounter a much greater quantity of water and pass through softer rocks than in England. At the same time it must be expected that in the future, sinkings of a character more closely allied to those in Belgium and Germany will have to be carried out.

Reference has hitherto only been made to the application of the Chaudron system to shafts in which the water has to be tubbed back. There are, however, other conditions to which the system will probably be economically applicable. Pits are frequently sunk at the dip of a coalfield, through large feeders of water, and in one of so shallow a depth as from 100 yards to 200 yards, the application of tubbing would be useless. In this case, instead of using expensive pumping machinery, which is liable to accident, and impedes the progress of sinking, cost might be saved, if this system of boring were adopted, and pumping machinery applied after the coal was reached.

To arrive at the relative economy in such a case as this, M. Chaudron has given an estimate for two pits which had been sunk a depth of 120 yards under the superintendence of the Author. M. Chaudron's estimate, inclusive of royalty, is about 33 per cent. less than the actual cost of these pits.

There are conditions in the sinking of shafts through aqueous strata under which it may be found more economical to use the old system, such conditions being:—1. Where the feeders met with are separated by compact beds of rock, on which wedging cribs can be laid. 2. Where the feeders are not very large (yielding, say, 800 gallons per minute), and where they can be contended with by engines intended as future winding engines.

The simplicity of the Kind-Chaudron process affords but little scope for the occurrence of accidents. The regularity with which the boring is conducted, the appliances in use for the safe and dexterous handling of the tools, the care with which the tubbing is placed in the shaft and made solid, and the general appearance which the works present of a minimum of moving plant, are all points which conduce to this result.

In conclusion, the advantages which the Kind-Chaudron system

of sinking shafts appears to possess may be stated as follows:— 1. A considerable saving in the actual expenditure on the sinkings is effected. 2. The expenditure of capital is lessened by the quick progress made through the water-bearing strata. 3. The abolition of all pumping machinery, and, as a consequence, the avoidance of accidents, so frequent and costly in sinkings where large and extensive pumping machinery is employed. 4. The saving of the heavy cost consequent upon the wear and tear of a large quantity of moving stock as used in pits sunk by means of pumps. 5. The sinkers work on a dry stage and not in water; they are thus enabled to work a much longer shift, and to apply their labour in a far more effectual manner. Their work furthermore is of such a character as to require less wages than are demanded by the practical sinkers, who would have to be engaged for the ordinary process. 6. The avoidance, by the use of solid rings, of the liability to leakage and breaking in of the tubbing, which occur with the vertical seams of the segmentary tubbing usually employed. 7. The pressure of water in the pit during the sinking prevents in a marked degree the sand or other loose strata from coming into the shaft during the sinking. 8. As compared with sinkings where extensive pumping machinery is employed, the saving of fuel, which in new districts where the cost of coal is heavy, is an important item.

It may be observed that as sinkings for coal in this country become deeper, and as they will necessarily encounter more water than heretofore, the cost of the shafts will form a larger proportion than at present of the total cost of opening out a colliery. Hence any system, like that described, which appears to promise saving of labour, economy of time, and a greater degree of permanent security, than the old system of sinking and placing the tubbing, merits the serious consideration of engineers.

The communication is accompanied by a series of diagrams from which Plates 12 and 13 have been compiled.

[Mr. E. Bainbridge

SINKING SHAFTS THROUGH WATER-BEARING STRATA.

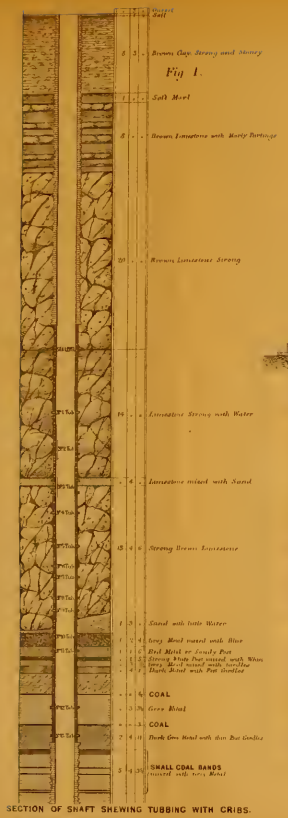


Fig 1.

SECTION OF SHAFT SHEWING TUBBING WITH CRIBS.

Fig: 4.

Fig: 5.

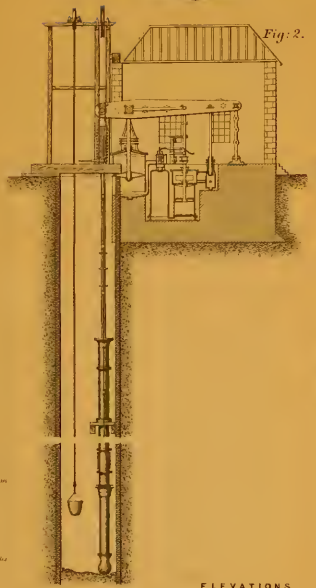


Fig: 2.

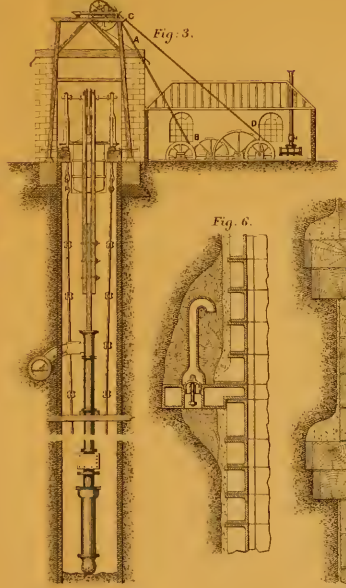


Fig: 3.

ELEVATIONS,
Shewing ordinary mode of contending with Water by Pumps during sinking.

Fig: 6.

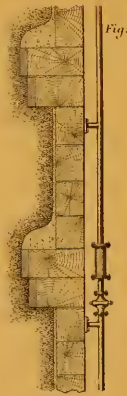


Fig: 7.

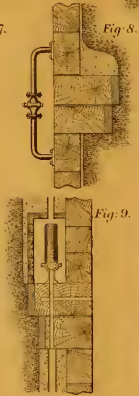


Fig: 8.

Fig: 9.

SECTIONS,
Shewing different modes of making connection between different sets of Tubbing to equalize the pressure.

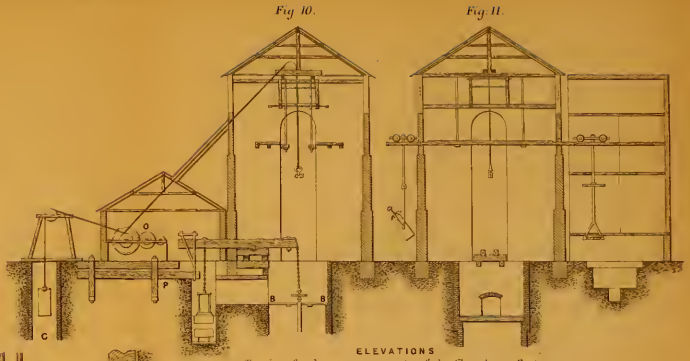


Fig 10.

Fig: 11.

ELEVATIONS
Shewing Surface arrangements of the Chaudron System.

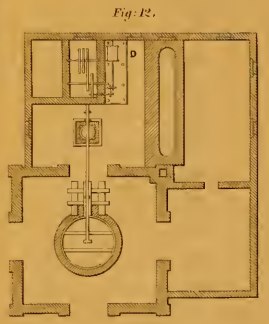


Fig: 12.

PLAN,
Shewing Surface arrangements of the Chaudron System

Minutes of Proceedings of the Institution of Civil Engineers Vol XXXIII Session 1871-72.

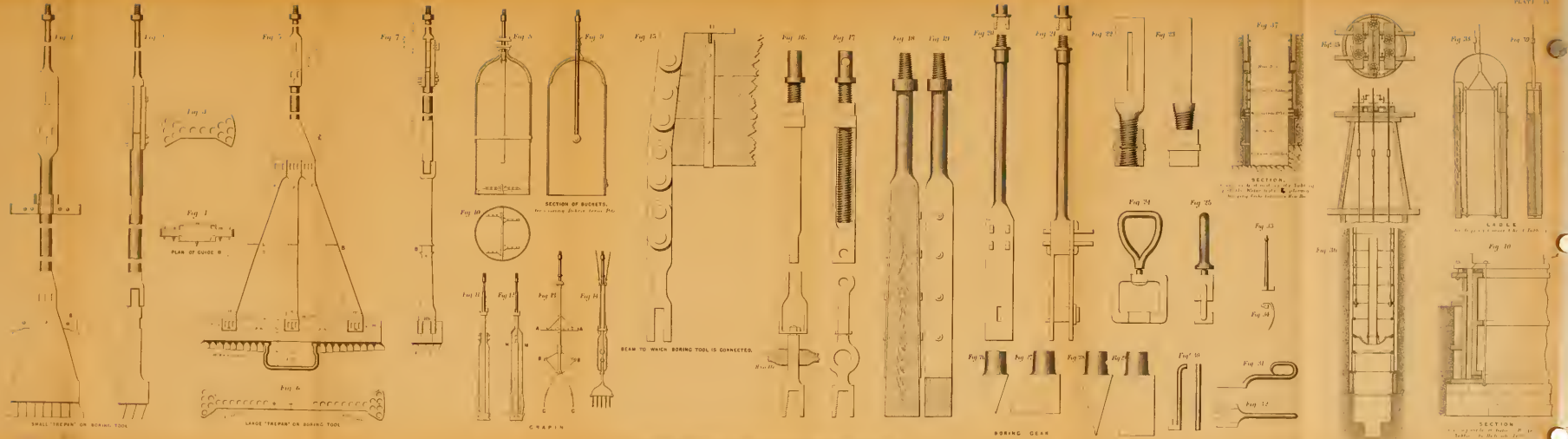


Fig 1.
Fig 2.
Fig 3.
Fig 4.
Fig 5.
Fig 6.
Fig 7.
Fig 8.
Fig 9.
Fig 10.
Fig 11.
Fig 12.
Fig 13.
Fig 14.
Fig 15.
Fig 16.
Fig 17.
Fig 18.
Fig 19.
Fig 20.
Fig 21.
Fig 22.
Fig 23.
Fig 24.
Fig 25.
Fig 26.
Fig 27.
Fig 28.
Fig 29.
Fig 30.
Fig 31.
Fig 32.
Fig 33.
Fig 34.
Fig 35.
Fig 36.
Fig 37.
Fig 38.
Fig 39.
SMALL "TREPAN" OR BORING TOOL
PLAN OF GUIDE B
LARGE "TREPAN" OR BORING TOOL
SECTION OF BUCKETS.
CRAPIN
BEAM TO WHICH BORING TOOL IS CONNECTED.
BORING GEAR
SECTION
EAGLE
PLAN AND ELEVATION
SECTION

Mr. E. Bainbridge observed, in reply to a question, that only two shafts were now being sunk by this system, these being at Maurage, near Mons.

Mr. T. J. Bewick contended that this apparatus was applicable to other sinkings besides those through aqueous strata, because the saving both of time and money was so considerable. If it was a question of getting rid of the material from the larger trepan to the smaller, that could be managed by allowing a quantity of water to remain in the sinking. He believed that all pits sunk on this method had proved successful. He should, however, like to be informed, whether when the moss box and tubbing were under high pressures the escape of water had always been prevented, and if not, what had been the means taken for clearing the shaft of the water? Also how the bed upon which the bottom of the tubbing was placed was made so true and exactly level, for the reception of the bottom cribbing, as to be perfectly water-tight; and as to the character of the rock on which this apparatus had been tried, and whether it would answer for limestones and other similar rocks. The progress through flints was very slow; but as these only occurred in irregular beds, perhaps it was not a fair test of what might be accomplished by the machine in more uniform hard strata. A great advantage in this system was the reduction of the amount of risk to the workmen, the chief of which arose from loose materials falling down the shaft in the ordinary way of sinking.

Mr. J. L. Thomas said, he had listened to the Paper with some curiosity, and considerable interest; the former as he had hoped to have heard of some shaft having been executed by this system in this country; and the latter because, of all the operations in which the mining Engineer was engaged, there was none which gave rise to greater anxiety, and none requiring the exercise of greater intelligence and care, than the sinking of deep shafts through what were termed aqueous strata. The Kind-Chaudron process described in the Paper was not new to him; for accounts of works executed on this system were interspersed through continental engineering literature. In vol. xviii. of the "Annales des Travaux Publics de Belgique," and in vol. xi., Series 6, of the "Annales des Mines," were descriptions of shafts sunk by this system, written by M. Chaudron himself. These papers were accompanied by details of the nature of the stratification sunk through, the rate of progress made, and the exact cost of sinking. In the volume of the "Annales des Mines" corresponding to the year 1869 was to be found an account of the sinking of a pit at the mines of Escarpelle, in the

coal-basin of the Pas de Calais; and of this operation, as it would supply an idea of the difficulties with which the Kind-Chaudron system was designed to cope, he would endeavour to give a very brief résumé. A shaft was commenced on the ordinary system, and sunk a few metres, but the water overpowering the heavy pumping machinery, a second shaft was undertaken contiguous to the first, and also supplied with pumping power. The two shafts at the end of two years had attained a depth of 18·27 metres and 23·09 metres respectively; and it was then found that the water was so abundant that the existing powerful machinery was unable to cope with it. The cost of the work up to this point had been 427,242 frs. In this extremity it was decided to continue the sinking by the Kind-Chaudron process. After the preliminary arrangements were made, the shaft was completed to a depth of 104 metres in about nine months. Of this time a little over six months were employed in actual sinking, the rest of the time being occupied in fixing the tubbing, in cementing behind it, &c. The total cost of the operations in this instance carried out on the Kind-Chaudron system was 208,681 frs.; and this sum included 47,434 frs., the value of the sinking plant; and the tubbing and "cimentage" figured for 87,282 frs.

The continental Engineers had now had this system of sinking practically under their notice for some years, but it had not been as extensively adopted by them as might have been expected. Taken as a whole, it appeared to be exceedingly well designed for the object in view. The failure of the moss box he regarded as a possible contingency.

Some large and deep borings had been carried out by the Engigineers of this country, notably by Messrs. Mather and Platt. In borings, the depth of which exceeded 300 feet, considerable delay and expense were entailed in raising, lowering, and coupling heavy rods. In Messrs. Mather's apparatus the rods were superseded by a flat hemp rope, to which the boring tool was attached. The advantages attending the use of a rope in place of rods was, that it could be drawn to the surface at the same rate as the kibble attached to the rope passing over the drum of an ordinary drawing-engine, and by this means much time, and consequently expense, were saved. He believed that Messrs. Mather's apparatus was capable of dealing with much larger bore holes than had yet been undertaken with it.

He agreed that there was no reason why the Kind-Chaudron system should be restricted to boring through what were termed aqueous strata, viz., absorbent strata in which the mass of the

water was pent up. He regarded it as also adapted to sinking through measures consisting of homogeneous rock, in which the water was more equally distributed—indeed, through any rock with which the boring apparatus *per se* was capable of dealing advantageously and economically.

One of the most useful features which characterised boring, in contradistinction to sinking with the aid of pumping-power, was that the water, which in sinking under the ordinary system was the most troublesome and expensive enemy to be dealt with, was by this process converted into a positive advantage, acting as a support and maintaining tender ground in situ, and preventing disintegration until the tubbing was fixed.

He understood M. Chaudron to give, as some of the advantages to be derived from his system,—

Complete isolation of the aqueous strata;—very great solidity of the tubbing;—considerable reduction in the cost;—economy of time;—amelioration of the labour of the workman; and possibility of traversing all water-bearing strata, whatsoever might be their nature and thickness.

Mr. John Cochrane asked the Author whether any difficulty had been experienced in sinking through quicksand, such as was met with in South Staffordshire, 25 feet or 30 feet thick? He apprehended, whether there was water in the shaft or not, when sand was present it could not stand vertically; and then he could not see how this machine could act. In dry material, nothing could be cheaper than ordinary open sinking, and no such expensive tools were required.

Mr. Bainbridge said M. Chaudron had as yet met with no sand in his sinkings, but he apprehended the process would be the same as in ordinary sinking through sand. The shaft had to be enlarged, an iron tube forced down, and the boring tool worked inside the tube. This was the manner in which M. Chaudron intended to pass through sand. The question of sand had to be dealt with in the same way, whether boring tools were used or not, and the sand, when once overcome, did not interfere with the working of the machine.

Mr. Hemans, Vice-President, expressed his surprise at the suggestion that this operation was as applicable to dry excavation as to excavation in water. The process was that of chipping the rock into dust, for it reduced all the contents of the shaft into fine dust under the teeth of the instrument. He thought that would be an extravagant way of proceeding in cases where there was no water. The economy of this system was in not taking the

water out. The shaft when at the bottom plugged itself upon this cushion of moss, so that the water could not rise under it, and all the water to be removed was the small quantity contained in the shaft; whereas, if tubbing were not adopted, all the water in the shaft might have to be removed, one hundred times or more, according to the permeability of the strata by water. To apply this machine to dry rock, it appeared to him, would be a most extravagant way of proceeding. The rock should be quarried and removed in large pieces, as in ordinary well-sinking in rock.

Mr. W. Shelford considered it one of the main objections to this process, that all the expenditure had to be incurred before it was known what the result would be. The sinking was made through water-bearing strata, and the water pumped out, and the work could only be tested after that had been done.

Mr. Bruce inquired how it was known when the bottom of the water-bearing strata was reached? He understood that below a certain depth there was no water, and at a certain point a solid base was reached on which to place the moss box. It had been said one advantage of this system was that, in order to reach the coal deposits, future sinkings would have to be carried to a much greater depth than at present; but if the water was passed within a comparatively moderate depth, sinking below that depth would not be influenced by this machinery. In the case of going through a stratum of loose sand, he did not see how it was possible to put the cement round the narrow space between the cribbing and the rock. He thought the box containing the cement must stick somewhere, having to go down 500 or 600 feet. Besides, it was very expensive putting cast-iron tubbing through the whole of that distance.

Mr. T. Wynne asked the Author how it was proposed to meet a case where the hard stratum under the water-bearing strata stood at an angle of 30° or 36°? He did not see any tool that would cut one side of the pit, and not cut the other. Very hard rock under the water-bearing strata would, in his opinion, throw both tool and cylinder on one side.

Mr. A. Chambers said he believed Messrs. Mather's boring apparatus was worked either by a rope or a chain; and that when the strata were at considerable inclination and hard, there was great difficulty in keeping the boring apparatus perpendicular. That was, however, avoided by the method under discussion, because in this case rods were used, and hence there was not so much liability in the apparatus to move out of the perpendicular.

Mr. C. J. Appleby said, apart from other considerations, the great weight of the boring tool, 16½ tons, working under the conditions described in the Paper, was likely to cut through almost any strata without fear of its getting out of the perpendicular.

Mr. T. M. Rickman asked whether the presence of water in the pit assisted the cutting power of the tool in the rock, or the contrary?

Mr. E. Bainbridge, in reply upon the discussion, said, the first, and perhaps the most important question brought forward was whether the Chaudron system could be adopted in strata which were dry as well as in those which were water-bearing. There were difficulties in the way. One was the amount of trituration which the rock underwent. Mr. Bewick suggested that the difficulty might be obviated by allowing a certain quantity of water to remain in the shaft; but another point had to be considered. As the sinking progressed, the quantity of rods that had to be used increased in number, and a long time was occupied in lowering and raising them. In a depth of 200 yards, probably half the time would be taken up in that manner, and in deeper shafts, from three-quarters to seven-eighths of the time would probably be thus occupied. In all cases when and where employed the Chaudron system had been successful; and he believed that success had been greatly contributed to by having each separate ring of tubbing tested by hydraulic pressure. Ordinary rings of tubbing, formed of several segments, involved a number of joints; but in the case of the rings used by M. Chaudron, which were 4 feet 9 inches high, there was much less liability to fracture. The rocks which had been bored through hitherto were, as a rule, more tender than those generally met with in this country.

It had been objected that the moss box might fail to act; but the interval between the moss box reaching its bed and the tubbing beneath being fixed was very short, and when the tubbing below the moss box was secure in its place the general arrangements of the shaft might be considered as strong as by the ordinary plan. The moss box as a water barrier existed no longer, but the wedged cribs took its place, securing or forming the base of the tubbing. He had asked M. Chaudron, with some anxiety, how it was ascertained when the bottom of the water-bearing strata was reached. The reply was, that this could only be ascertained either by a preliminary boring, or by judging from the strata passed by pits sunk on the old system, where such existed. It appeared that in all cases where the process had been applied, expensive sinkings had been made by the old process, and by that means the position

of the rocks which yielded the most water was known. As sinkings through water-bearing strata became more frequent, and as more pits were sunk through the Permian and other measures, the capital required for such purposes would in the future bear a larger proportion to the total capital than it had done in the past. The sinkings which would probably at some not remote date be prosecuted in the Eastern Counties of England would undoubtedly pass through a large quantity of water; and while shafts now represented about 10 per cent. in the cost of winning coal, they would in the future possibly represent nearly 25 per cent., unless some better system of sinking was resorted to.

The trepan, being 16½ tons in weight, was sufficiently heavy to prosecute the work regularly whatever might be the inclination of the strata. In some shafts inclined strata had been met with, and successfully pierced.

He had no idea of presenting a novelty when he brought this Paper before the Institution. This was an important branch of engineering, which, for the last ten years, had been well known and approved on the Continent. What he brought as a novelty was this—he had endeavoured to show the important bearing of the combination of inventions described in the Paper, on the economy of coal-mining, when sinkings through water-bearing strata had to be made. The figures given showed that the total cost under the old system was £114 per foot, whilst with the Chaudron system it only amounted to £22 per foot; and the striking difference between the economy of the two systems, as evinced by these data, was his apology for having brought forward the subject. The rope was the chief point of difference between the Mather and Platt system of boring and Kind's; and it was especially the rope which enabled them to work faster. He considered, however, that it would be difficult with a weight of 16 tons to use a rope with advantage.

March 12, 1872.

T. HAWKSLEY, President,
in the Chair.

No. 1,326.—"On the Soonkêsala Canal of the Madras Irrigation and Canal Company."[1] By JOHN HERBERT LATHAM, M.A., M. Inst. C.E.

THE object of this Paper is to give a general description of the canal between Soonkêsala and Cuddapah, recently constructed for irrigation and navigation by the Madras Irrigation and Canal Company; and also to direct particular attention to the mode of safely constructing high banks for canals or tanks, illustrated by that work.

It seems not to admit of doubt, that the countries possessing the greatest powers of production are those in which the yearly rainfall is concentrated into a few months; as it is certainly beyond doubt that the innate resources of such countries are up to this time the least developed. Settled warm weather is the safest for crops at every stage of their sprouting, growth, and ripening; and, not only in England but in India, it is found that crops grown during uncertain weather, as all unirrigated crops must be, are nearly as often and as severely injured by rains or floods as by drought. Egypt, as far back as history exists, has been a country of settled weather, and also notorious for its fertility; yet that country, even as far as irrigation has gone, can scarcely be called more than half developed. To fully develop the productive powers of land three things are needed: first, settled weather, which art cannot give nor control, and can only turn to account; secondly, irrigation, which must be controlled by art, though a supply must exist upon which art may operate; and, lastly, manure. When it is considered that good land, under constant cultivation in a settled climate, may utilize a ton of guano an acre a-year, besides more bulky and less potent manures, it is impossible not to think what a population the world is capable of supporting, and how unnecessary it is that so many mouths in the most industrious nations are insufficiently filled.

From time immemorial the native inhabitants of the Madras

[1] The discussion upon this Paper occupied portions of two evenings—having been resumed on the 9th of April—but an abstract of the whole is given consecutively.

Presidency have spent large sums in the construction and management of undertakings having for their object the application of water to irrigate fields and gardens. The only native engineering buildings in the country consist of works of irrigation, fortification, religious worship, and shelter for travellers; and of these, in magnitude and importance, works of irrigation rank the first. These have been of three chief kinds, viz.:

I. Wells, which are generally large square pits lined with stone, from which water is raised by simple machinery and delivered on to the fields.

II. Tanks or reservoirs, which are filled by rain-water, and from which the water flows through sluices on to the fields.

III. River channels, of which the canal under review is one. These are the most prized of all the methods, and are stated to give 25 per cent. more crop per acre than either wells or tanks. In some few cases tanks were supplied from river channels, as at Nundloor, Nellore, &c.

River channels were constructed for turning the water of rivers on to the fields in such a way that a nearly constant supply should flow down them, whatever floods should come down the river. Unless so constructed they required to be annually closed, near their entrance or offtake from the river, by a bank; for head sluices were rarely made. The first object, viz., an offtake of constant supply, is accomplished in various ways. If the river-bed be a broad ill-defined one of deep sand, channels are cut parallel to the river along its margin, having their bed lower than the summer level of the water in the sandy river-bed, the spoil being thrown towards the river to make a flood bank, and prevent the river floods flowing into the channel. The up-stream end of this flood bank would abut upon any natural sandhill or other eminence. After running down a mile or two, the channel is given a less fall than the river, and is gradually brought out of the river-bed. Such channels flow by filtration, whether the river be quite dry or in full fresh. They are numerous on the rivers Chêyêr and Chittrawutty. On the other hand, if the river-bed be rock, a constant offtake may be secured by carrying a rough weir of loose stones across the rocky bed of the river, and returning it downwards under each bank on the margin of the river-bed, until out of the reach of floods; as at Hoossoor, Darojee, &c. The upper side of each return forms the inside of the channel, and is well lined with earth and vegetation. The weir and returns have their crests all at the same level; and the channel runs with a slight fall from the ends of each return.

Where the formation of the ground is such that a channel of the former sort in a sandy river would be carried away yearly, the side channel is abandoned, and the offtake channel requires to be banked across its mouth yearly to prevent the floods running down it and doing damage. This can be conveniently done at the close of the dry season; and when the rains are over and irrigation is needed, the entrance is cleared and a catch bank of sand is constructed in the river-bed to divert the water of the river into the channel. This catch bank is run farther and farther out upward across the stream as the river falls, and at an angle of about 30° with the direction of the stream, so as to keep the supply to the channel constant, until the bank may perhaps extend right across the river. Similarly, where the formation of the ground is such that a weir in a rocky river cannot be returned along the rocky river bank, the channel has been run directly from the end of the weir and at once completely banked off from the river. The case or cases of head sluices being built to such channels before the English rule are so few that it can be hardly called Hindoo practice to build them at all, so far as the Author's personal experience goes. To prevent excessive damage from the river floods, the entrances of such channels are generally cut very narrow, and, if possible, in solid rock; and numerous waste weirs are placed along the channel in the course of the first mile or two in order to get rid of the surplus water poured in by floods through this narrow entrance.

English Engineers soon adopted the rule of placing head sluices across all river channels at or near their entrance. They also extended the use of weirs to sandy rivers as well as to rocky ones, as more effective than the annual bank of sand. Scouring sluices were inserted (not always judiciously) in the weirs, to keep down the silt in the pond above them, and to clear the face of the head sluices of the channels led off from the pond. These scouring sluices are invariably in Madras called "undersluices," whether in the weir or not, though, in the latter case, no water goes over them. Indeed none of the so-called "undersluices" of the Madras Irrigation and Canal Company are strictly undersluices, but they are merely low-level scouring sluices built at the end of the weir, and generally in a line with it.

By great energy some of the engineers of the Madras army induced the Madras Government tentatively to adopt these innovations in situations admirably chosen for the trial; and weirs were constructed at the head of all the considerable deltas—as the Cauvery, Kristna and Godavery—of rivers having a sufficiently

constant flow to irrigate fields for one crop at least of rice each year. The channels from these weirs run along the uniform slope of the delta country, rarely crossing any considerable drainage, and diverge like the rays of a fan from each end of the weir.

The first result of the great success of these innovations was the extended use of similar permanent weirs at the heads of channels, for rivers of very short and uncertain flow, which, instead of running to the fields, run into a series of ordinary village tanks. Of such a kind is the Nellore Anicut across the Pennêr. By its means the floods of the Pennêr are distributed; but, as in London, each householder, so in Nellore, each village, irrigated by the weir, has to provide and keep in repair its own tank to receive and store the intermittent supply, as well as an escape weir for the passage of surplus water to the next tank below. These tanks rarely exceed 1 mile in breadth and 9 feet in depth of water. Other rivers have received, as the Palâr, &c., or deserve, as the Soonamooky, &c., similar treatment.

While the rebuilding of the Nellore Anicut, since it was last carried away, was making progress the "Toombuddra project," for using the inland rivers for irrigation, was adopted by the Secretary of State, so far that interest was guaranteed on £1,000,000 to be raised by the Madras Irrigation and Canal Company, towards carrying out a definite portion of that project for irrigation and navigation combined. The objects of the Toombuddra project, of which the Soonkêsala canal is a portion, were two: the first, continuous irrigation throughout the year of three large areas, of which the largest lies in the Bellâry District, the next in the Koondêr Valley, and the other in the Nellore District. The second object, apparently necessary to the success of the first, was a means of communication by canals, by which the produce of these areas could be sent to a market more cheaply than by cart or railway, more expeditiously than by cart and more securely than by railway. In order to maintain irrigation, the autumn and winter supply of the river Toombuddra itself was to be directly distributed to the fields over these areas, and the surplus autumn rainfall was to be stored in large tanks near the sources of the Toonga and Budra in the western hills, in sufficient quantity to maintain the irrigation when the river Toombuddra (Toonga-Budra) itself failed. Navigation could thus be maintained along the line of irrigated country, either in the channel used for the distribution of water or in separate canals. Navigation is particularly suited to India, both on account of its cheapness and security. Two arrangements seem necessary for security, viz., that the goods should not be transferred

from one vehicle to another during the whole journey, especially where other similar goods are being similarly transferred; and that the owner or his agents should be allowed to accompany the goods in whatever vehicle they be placed, and that he should be able to do so in comfort. It is not petty pilfering, but wholesale change of large consignments of grain or cotton, of which the Indian merchants express fears and relate their experience.

This Toombuddra project is one of great importance, not only for India but generally, on account of the hitherto insurmountable difficulties it is intended to meet. These are three in number. In the first place, it proposes, by the mere offer of water, to induce a vast population of ill-educated and poor ryots or cultivators to forsake in great measure the cultivation of dry grain—the only cultivation they know either by experience or tradition—and to undertake a more expensive and intelligent system of agriculture. No doubt, wherever water has already been used from time immemorial, as in the delta countries or in Scinde, it is highly prized; and additional security or extension of the supply is there immediately taken advantage of by the ryots, if the terms suit them. But in the parts of Bellâry, Kurnool, and Cuddapah proposed to be supplied with water by this project, it is not so much the extension, as the introduction of wet cultivation that is aimed at; not the irrigation of dry crops of corn, as on the Ganges and Jumna canals, but the superseding of dry crops by wet, and that without any of the compulsion inseparable from Government works.

A second difficulty is the necessity for the provision of a constant supply of water, by storing it in sufficient quantity for all the work, for use in the dry months. For this purpose it will be necessary to construct tanks or reservoirs, having banks as high as, and longer than, any constructed in historic times, and to provide these reservoirs with surplus weirs or sluices, which on account of the great uncertainty of rain in India, and the great range through which the yearly discharge varies, will need to be of extraordinary discharging power.

The third difficulty lies in the adverse character of the country. Throughout its whole length the Toombuddra valley is crossed by ridges of hills, which render it difficult to carry off channels from the river. Hence the canals executed or projected by the Company have some very heavy cutting and banking before they can be led away from the river so as to command a large area of country. The ridge of hills which crosses the Kristna valley just below the

confluence of the Toombuddra and Kristna, is about 25 miles wide, and its summits are nearly 3,000 feet high. The river passes through this ridge in a narrow and sinuous course, between high and often precipitous banks, for a distance of upwards of 60 miles. Neither navigation nor irrigation could be carried through such an obstruction. Instead of being surmounted, the flank of the ridge is turned by a canal on the level of the watershed dividing the Toombuddra basin from that of the Pennêr, which flows into the sea at Nellore. The canal already completed has its off-take from the Toombuddra, at Soonkêsala, 17 miles above Kurnool, and after a tortuous course of 75 miles, in which it passes over the river Hindry and three other considerable tributaries of the Toombuddra, at an average cost of £8,000 a mile, arrives near Metacondâl, at the watershed between the river Böanâssey, a tributary of the Kristna, and the Kâlî or Caulee, a branch of the Koondêr, a tributary of the independent river Pennêr. There can hardly exist a valley more favourable for irrigation than the Koondêr. The soil is good, the valley broad and flat, and the disposition of the levels, or slope of the ground, excellent. Indeed, when once the Metacondâl watershed is passed, irrigation becomes almost as easy as it is from the weir at the head of a delta country, and the cost of the canal was, for the rest of its course, only £2,900 a mile.

To pass on to a description of the canal itself. (Plate 14.) The Toombuddra project was first brought forward by Colonel Haviland, but it was not till 1858 that the Madras Government, on the report of General Sir Arthur Cotton and other Engineers, selected it as the first work to be undertaken by the Madras Irrigation and Canal Company. In 1861 that Government limited the work of construction under the guarantee to the canal between Soonkêsala and Cuddapah, and the weir at Someshwaram; and in 1866 made terms with the Company for completing the canal between Kurnool and Cuddapah by the 1st July, 1871.

The character of the canal may be sketched as follows: the first 75 miles is calculated to carry 400,000 cubic yards of water per hour at the head at Soonkêsala, and, after gradually parting with about 100,000 cubic yards for irrigation, to convey at least 300,000 cubic yards an hour through the Metacondâl cutting at its other extremity. There 255,000 cubic yards an hour may be discharged into the Kâli, and 45,000 cubic yards carried down the continuation of the canal. Of the 255,000 cubic yards an hour poured into the Kâli, the canal is calculated to take up 100,000 cubic yards at Jutoor and 50,000 cubic yards at Râjoli, leaving above 100,000

cubic yards of water per hour for the insignificant irrigation below Cuddapah and for Nellore.

The canal begins at Soonkêsala with a weir, Figs. 3 and 4, Plate 15, across the river Toombuddra, 1,500 yards in total length of clear over-fall, which is broken into two lengths by an intervening island. The weir stands upon the rocky river bed, and is formed of three patterns, viz.: 1. Of solid rubble masonry of gneiss, trap and quartzite boulders, of the form Fig. 3. 2. Of gravel concrete, with gneiss rubble facing in front and rear, of the same section. 3. All recent portions are of solid gneiss rubble masonry, with a facing on the lower side of Kurnool limestone ashlar, which averages $\frac{3}{4}$ yard thick where exposed to concussion. Fig. 4. Patterns Nos. 1 and 2 have a front and rear batter of 1 in 8; while No. 3 has an upper batter of 1 in 4, and a rear face vertical. All are 8 feet broad at the top, and coped with dressed limestones 1 foot thick, of which every alternate one is a through stone 8 feet long, weighing about $1\frac{1}{2}$ ton. The mortar throughout is of Kurnool kunkur, except the joints of the coping, which are of Portland cement. The coping is joggled wherever the anicut (which is not straight, but follows the line of highest solid rock) is concave in plan on the up-stream side. No part of the anicut formed on any of the above patterns, either with or without the coping, has ever failed. The height varies from 6 feet to 26 feet, and averages about 18 feet; and the highest registered flood rose $7\frac{1}{2}$ feet over the crest.

From the pond above the Soonkêsala weir the water is admitted into the canal by a head sluice without any lock. The face of the head sluice is kept clear by the scour of ten under-sluices at a lower level in the weir, the stream to which is forced against the front of the head sluices by a long curvilinear groin. The minimum cross section of the canal for the first 75 miles has a 90-feet bottom, with 2 to 1 side slopes. For the first 45 miles the fall per mile is adapted to secure a discharge of 400,000 cubic yards of water an hour, if requisite, without increasing the depth of the water to more than 8 feet. Below the 45th mile, the canal being in good soil, and lying on easy slopes with limestone or shale subsoil, a depth of 9 feet of water is allowed. At the 75th mile the canal passes through the watershed between the Toombuddra and the Pennêr rivers; and thence the natural water-course becomes the main supply channel, under the successive names of the Kâlî, the Koondêr, and the Pennêr. From this natural main supply channel the water is taken at four points, viz., Lockinsula, Jutoor, Râjôli, and Adanimayapilly, by the simple process of throwing

weirs across it, with under-sluices in the weirs to keep down the silt, and head sluices across the channel to control the supply and entrance locks.

The first branch irrigating channel forms the main canal from the 75th to the 95th mile. Its head is formed at Lockinsula by blocking up the water-course (there so rudimentary as to have been used for a village road) by a bank with scouring sluices, and turning the main supply over a natural weir of rock, whence it joins the old water-course below. The head sluice and lock are adapted for working this branch with a depth of 6 feet of water, when the irrigation becomes sufficiently extended to require it in the Nundi-cotacoor and Nundial Talooks, and at this depth the flow will be 45,000 cubic yards an hour. This canal is an irrigating channel for the first 6 miles only. Below that it is a still-water canal, with a fall of 180 feet 5 inches, overcome by seven double-chambered locks and five single-chambered locks. The greatest drop in any one double lock is 21 feet 8 inches, and in a single lock 13 feet. The chambers are 120 feet long, by 20 feet broad. The canal is 45 feet wide at the bottom, and the minimum depth is 5 feet.

The second branch irrigating channel takes its supply from the main stream in the Kâlî at Jutoor, and forms the main canal from the 95th to the 146th mile. It has a very wide area of distribution in the Nundial, Seriwell, and Koilcoontla Talooks of the Kurnool district. It is intended to distribute 130,000 cubic yards of water an hour, if required; but to do this 2 feet height must be added to the banks over the first 20 miles of its course. In its present form it is adapted for carrying about 100,000 cubic yards an hour; and this is probably enough to supply rice for all the local demand for food, leaving the cultivation of cotton and indigo, for which the valley is celebrated, more room than is available while dry grain has to be grown for food. Already the Company has irrigated a greater area of dry than wet crop in this valley. A good indigo crop is of more value as an article of commerce than a good rice crop, but hitherto indigo cultivation has been so precarious that a really good crop might not be obtained once in six years. No crop more needs and repays irrigation. The head works consist of a weir (Fig. 5) of solid limestone in rubble masonry founded on soft shale, and of head sluices, the face of which are scoured by under-sluices in the weir by help of a training wall and of an entrance lock. The weir is 6 feet broad below the coping, and has a batter on the upper side of 1 in 4; the rear face, which is ashlar, descends vertically into a trench or

water cushion, hollowed out of the shale and lined with limestone masonry. This water-cushion is narrower than it should be. The coping is protected from floating timber by a foreshore of rubbish from the shale excavation. This branch is adapted for a depth of 6 feet of water down to the first drop lock in the 118th mile. Below that lock, water is passed, for a limited extent of irrigation, round ten locks, and at the eleventh lock (130th mile) all irrigation ceases. The canal between the 118th and the 146th mile consists of level reaches adapted for a depth of 5 feet of water, and contains seventeen locks, with a total fall of 187 feet 6 inches, and a maximum fall in any one of 14 feet. The bottom breadth throughout is 50 feet.

The third branch irrigating channel takes its supply from the main stream in the Koondêr at Râjôli. The 146th mile of the navigable canal falls into this branch about $\frac{1}{4}$ mile below its head, and is continued to the 180th mile. The Râjôli weir is of solid limestone in coursed rubble masonry, 5 feet thick at the top, with a batter of 1 in 2 on the upper face and plumb on the lower face. (Fig. 6.) It stands on thick beds of solid limestone. With a depth of 5 feet of water in it, the canal will discharge 50,000 cubic yards of water an hour, the bottom breadth being 50 feet. The irrigating channel ceases at the first lock in the 172nd mile, and thence to the river Pennêr is a still-water canal, which falls 90 feet 6 inches, by means of nine locks, of which the greatest drop is 13 feet.

The fourth branch is a length of 8 miles of canal at nearly a level, supplying a small area of irrigation. It is, in fact, the first 8 miles of the projected continuation of the canal into Nellore. It is adapted to distribute for irrigation about 5,000 cubic yards an hour of water, and has a bottom breadth of 50 feet. The headworks consist of a weir[1] across the main supply in the Pennêr, with head and under sluices, and entrance lock. The river gates of the entrance lock are 25 feet high, and are the heaviest on the canal. The weir for a short portion of its length is of solid limestone in rubble masonry founded on rock; but the greater proportion of it is founded on sand, and consists of a masonry slope supported on the upper edge by a double row of wells and on the lower edge by a single row of deep wells. There is a longitudinal row of wells along the middle also. The slope is 1 in 11·75; and below the

[1] Mr. H. P. Higginson, M. Inst. C.E., has presented to the Institution a description of this weir. It was not possible to read this communication during the Session 1871-72.

slope is a dry rubble apron 105 feet broad. The canal terminates at a distance of 1½ mile from the Madras railway, and 163 miles from Madras.

Besides the weirs, some of the masonry works on the canal deserve notice. The Hindry aqueduct carries the canal 90 feet broad and 8 feet deep over the Hindry, at an elevation of 32 feet, by fourteen 40-feet arches, the length between the abutments being 651 feet. The lowest headway, at full water, under any bridge over the canal, is 15 feet; the smallest width, in locks is 20 feet. The under bridges have a width of 30 feet, except in two cases, where it is 25 feet. The lock chambers are 20 feet by 120 feet in the clear, and are adapted for working with a depth of 5 feet 6 inches of water, though they will work with less. The filling and emptying sluices are a pair to each pair of lock gates, *i. e.*, four to each single lock. Each sluice has an opening 4 feet square, and the ratio of the inlet ports to the sluice and to the outlet ports is as 5, 4, and 8 respectively.

The grade or fall of the canal where it is taken down the irrigating channel varies between 18 inches a mile in one or two deep cuttings, and a level in the tanks formed where the canal is carried over an open valley, by damming it across. In other places it is usually from 4 to 6 inches a mile. The last seems to be the most suitable fall where the cuttings and banks are of cotton soil unprotected by revetment of any sort; but it is impossible, without further experience, to say whether a more rapid fall would not be better. The more rapid the fall, the less silt will be deposited, but the more current there will be against ascending boats. Hitherto the silt has given but little trouble, and it seems likely that an annual outlay of £1,000 will suffice to remove all deposits of silt.

The lock sluices are simple cast-iron shutters running on wheels 8 inches in diameter. When quite closed, however, the shutter bears on the cast-iron frame or seat. They readily are raised by a rack by two men in a few seconds, or by one man where balance weights are attached.

No measuring sluices are needed. Two sizes of sluices for irrigation are used, besides some small ones, closed by hand, in the first three sections. The smaller size is 18 inches wide and 1 foot-lift, worked by turning round a vertical screw lifting a cross-head, to which the cast-iron shutter hangs. The larger has a lift of 3 feet 9 inches, and is 5 feet broad, the shutter being made of wood; and it is raised in the same way as the smaller ones. Each turn of the screw raises the shutter 1 inch, and one man can easily

work it against an average head of water of 6 feet. The raising gear and cast-iron grooves of the larger size cost £11 4*s*., delivered in London on board ship, and the smaller size, including iron shutter, £5 7*s*. The lock valves with crab, shutter, and frame complete, cost £36 each; while the gates complete in place cost about £2 11*s*. per foot drop.

Though the masonry works, and especially the weirs, contain a great variety of work, the chief interest and novelty in the construction of the canal is, undoubtedly, the mode of forming the banks. These range up to a height of 50 feet from the ground surface of their site to the water line. They are upwards of 35 feet in total height in the 13th, 18th, 22nd, 23rd, for nearly half the 24th, 29th, 32nd, 33rd, 34th (in these last 2 miles ½ mile of bank is 40 feet high), 48th, 54th, 58th, and 63rd miles; while in the 26th and 27th miles the bank exceeds 40 feet high. These banks are always on sloping ground, so that the height above the outer toe is more than the nominal height. Their formation in the above cases is as follows (in all cases the single bank is reveted or shingled on the inner slopes):—

Simple filling only in miles 5, 13, 22, 23, and part of 24, 32, 40, 54, 58, 63.			
Masonry wall, Fig. 7, in miles			24, 26, 28.
„ face wall, Fig. 8, in miles			26, 27.
„ revetment, Fig. 9 „			18.
Puddled bank,	Fig. 10	„	24, 33, 34.
Puddle core bank,	Fig. 11	„	26, 29.

The banks of the sections Figs. 7, 9, and 11 came into the Author's hands in 1865, as finished works, but have since been strengthened or raised. In Fig. 7, the rear wall is almost superseded by the backing of dry rubble added behind, so that the front wall acts as a face-wall to the mass of rubble behind. This is found a very efficient kind of wall; but it is right to mention that a portion of wall of this section was carried away during an extraordinary flood in August, 1870, which rose over the wall and, probably, cut down the ordinary bank at its junction with the end of the wall. The bank represented in Fig. 11 was originally constructed—as shown by the dotted lines—without the foreshore of puddle, and with merely a vertical central core of puddle 9 feet thick, extending from top to bottom, between two slopes of hand-packed rubble. The objection to this proved to be that the vertical core, being held by the packed rubble walls, could not settle. Hence if, on first filling the canal after a dry season, the water penetrated through some crack in the core, it would extend the crack, by wearing it wider

and deeper; while the puddle above would stand in an arch. No breach ever occurred from this cause, but excessive leaks took place in two cases, before the cracks could be reached through the hard puddle above them. A puddle foreshore was therefore added, in a position more easy of access than the puddle core.

The strongest and best sections are those shown in Figs. 8 and 10; sections adopted after the experience of two seasons in the working of banks of all kinds. The Author estimates the efficiency of these as so nearly equal, that the choice between them may be a question of cost. The only objection to the face-wall is that the bank cannot be raised, when once the wall is built, without carrying up the wall to a narrower width than 2 feet, or at least increasing the weight on the original wall by the addition of the material required to raise the bank. Hence, if enlargement of the canal be anticipated, the wall has to be built of a stouter section from the first. No portion of this face-wall has cracked or shown any signs of weakness; nor, though unprotected in front by either plaster or puddle, is the leakage more than just sensible. The puddled slopes are even tighter than the face-wall, and have proved efficient even when the bank is of the worst kind of white and grey clay, mixed with salts of lime and soda, and such as to absorb water readily. It may be thought more liable than a wall to injury from vermin, but no difficulty nor accident has yet occurred, and any defect is more readily repaired, and is less dangerous than in a wall; and this remark applies to defect from bad workmanship as well as from external violence. The total length of masonry walls in the banks is but a few chains short of 5 miles, and the puddled banks are nearly of the same extent.

In estimating the probable stability of a bank composed of soil thrown up, without either selection or puddling, when first exposed to water, a few first principles require to be borne in mind. Failure will take place either from the soil taking a flatter slope, when acted on by the water, than it originally stood at in the bank, or from leaks forming holes through the bank and ultimately destroying it. The Author has successfully stopped leaks 2 feet 6 inches in diameter, occurring at a height of 12 feet above the ground; and, on the other hand, has had the rear of a bank slipping down to a slope of about 1 in 10 also readily repaired. A little consideration will show how such casualties may be best treated; and lastly, how, by a careful construction of the bank, they may be avoided altogether.

It is necessary, in treating failures of banks, to get rid of the notion that, in practice, soil acted on by water becomes really

viscous, *i. e.*, chemically semi-fluid. The action of water for all practical purposes is mechanical. It is true that the presence of salts causes dry earth rapidly to absorb water to which it may be exposed; and the subsequent deliquescence of the contained salts may leave the soil in a thoroughly boggy state. But such soil only requires mechanically draining (perhaps no easy matter) to restore it to firmness; and it will then be freed from the salt, which will have been carried away in solution. The flattest slope taken by dry material is probably that of ground quick-lime, as it runs dry from the grindstones, when it will run nearly flat; and generally the natural slope at which dry material, deposited at hap-hazard, will stand is steeper in proportion as the particles are angular and rough, and flatter in proportion as they approximate to polished spheres; in the former case hardness of each particle or piece secures a maximum steepness of slope, in the latter case a minimum. The effect of a little moisture is virtually to increase the roughness of the particles, supposing no chemical action; the cohesion of small surfaces in contact being increased so much, that if the particles are small the material may stand vertically when damp, or at an overhanging slope. Excess of water may have, however, a very different effect, which will depend on the nature of the material. Thus a mass of rubble or gravel consists of materials of such a size as to be unaffected by the presence of water, as far as regards the relative position the particles are disposed to take; except only when the flood of water is so violent as to displace them by mere force of impact. Again, clean sand may be defined as a collection of insoluble particles, so small that, though after being thoroughly wet much of the water, if allowed, will drain out of it, yet enough will remain to increase cohesion, and so much as to equal or exceed the force of gravity on any particle. But clayey earth has its particles so fine as to retain by cohesion a sufficient quantity of water to separate, or nearly separate them, and to render the mass apparently viscid; and so it will remain until the water be squeezed out by pressure or dried up by heat. It may require intense pressure or heat to render such a material really dry; but a moderate amount of either may render it very hard. When really dry, the material will have become stone, or so like stone that the particles will not separate if again exposed to water; but if only moderately dry, as it is found in banks, it is possible that, when water is admitted into the crevices or pores of the material, it may so loosen the particles as to make them easy to separate, and unable to resist the slightest action of running water. This may happen even while the

cohesion remains so strong as to check and practically resist the passage of water through the body of the material.

The two dangers of slips and leaks to which a bank is exposed, and the mode of meeting them, are the following. In the first place water may be forced by pressure into the accidental interstices or fissures in sand or clay faster than it can drain or dry out of it; as where the outer slope of a leaky bank is made of sand, or where a bank is thrown up entirely of moist clay, and the greater weight on the centre squeezes out water contained in the central portion and forces it into the slopes. In both these cases slips of the slopes are likely; and they take a flatter slope than that at which they first stood. The danger from leaks is when water obtains a free passage, either through a crack or a burrow, without meeting any resistance sufficient to hold it back against the head under which it advances. The action of such a stream may enlarge the opening until the bank is destroyed. To stop a slip, either the water must be tapped by a drain before it enters the slope, or the slope must be artificially supported by a weight sufficient to prevent its movement. In the case of water flowing through a crack or burrow, no danger will result unless the material be tough clayey soil. A sandy soil soon falls in, as Fig. A will show, for the bed of the cavity will absorb the water, and the material will run to so flat a slope, and the sides, right and left, will be undermined so fast, that the top will fall in from the surface of the bank before it can attain any magnitude. In a tough loamy clay a crack is much more dangerous, for the soil is nearly impervious, and the stream will simply soften and carry away the bottom and sides of the burrow with which it comes into actual contact (Fig. B), and may cut its way down without widening the cavity sufficiently for it to fall in, even though it meander about and cut caverns 5 or 6 feet in diameter. The quicker the stream the more vertically the sides will stand; so that a leak of long standing is generally found to have cut a steep, narrow way nearly down to the level of the ground near the centre of the bank, and then to have made a series of wide chambers on its less rapid passage to the rear. Such leaks are best stopped by filling the caverns in the rear with gravel or rubble, and at once cutting

Fig. A.

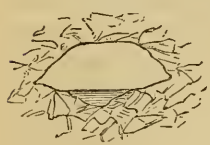


Fig. B.

down to the leak on the water side of the bank, and puddling it up on that side.

But the real problem is to make a bank which can neither slip nor be cut up by leaks; and may be safely filled after being dried for a couple of months by a mean daily temperature of 98° Fahr. in the shade, that of evaporation being 70°.

The consideration of this problem is the more necessary owing to the wholesale condemnation of earthen dams of above 65 feet in height, by M. Graeff, Engineer in Chief of the Ponts et Chaussées, in 1866.[1] This condemnation is disproved by the long existence and security of the dam of Cumbum, 102 feet high, under 94 feet depth of water. It may however be interesting to show, that a scientific and practicable theory exists for the construction of earthen dams; and it only remains to bear in mind, that a given quality may be secured, with less risk of defective work, in earthwork, with at least as much certainty as in masonry.

Before a bank can be safely exposed to water as above, the following conditions must be satisfied:—

1. The greatest possible leakage must not carry any material out of the bank.
2. It must be impossible for any burrow or crack to be made right through the bank.
3. The impervious part of the bank must be secured in its place, so that neither settlement can breach it, nor leaks through cracks which will occur in it carry the material out of place.
4. The impervious part must be encouraged to settle or shrink so as to close any cracks which may occur in it.
5. It must be easy to detect and overhaul any bad puddle.

It will be found, in practice, that when a bank fulfils these conditions, the entrance of water into any part of the bank is more difficult than its exit, and that in consequence the head of water upon the bank tends to press upon and tighten up every layer of material in the bank—a result that tends very much to increase the stability of every part.

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[1] "It is not necessary to consider the plan of constructing dams of earth, which are things of chance when they attain a height of 20 mètres (65·6 feet), and it is out of the question to use this construction for a height of 50 mètres (164 feet), which we have now under consideration."—Fife's translation of Graeff's Report* on the Dam of Furens, &c., in "Selections from the Records of the Bombay Government—Irrigation Series.—No. ix." 8vo., Bombay, 1869.

* This Report appeared in the "Annales des Ponts et Chaussées." 4e Série. Tome xii. pp. 184–211. 8vo., Paris, 1866.

It may be well to consider first how a bank should be theoretically constructed without any puddle at all; and, for this purpose, as round numbers are convenient, a bank 200 feet high will be taken merely as an illustration. It may be observed, to start with, that though the theoretical conditions of quality and arrangement of soil may not be absolutely attainable in practice, yet the margin of safety is so large, and the modifications permissible so ample, that any condition of security can, in fact, be attained in practice. Again, it is well to premise, that not only clean sharp sand and small gravel, but also these materials, after having their interstices silted up with a tough matrix of clay or puddle, present an insurmountable obstacle to the burrowing of vermin and to cracking by heat.

Let Fig. 13, Plate 16, represent a vertical cross section of a perfect filter in a prismoidal or wedge-shaped trough, whose sides contain an angle of 60°. By its being perfect, let it be understood that, whatever depth of water be placed upon it, the water alone moves as it passes through the filter; and that the material of the filter is arranged in horizontal layers, beginning with fine sand at the top, and then becoming successively coarser until the lower angle contains large rubble blocks, in such accurate proportion that the water flows through freely enough not to resist that behind it, but not so freely as to leave any apertures.

If the upper layer of fine sand be as deep as the water placed upon it, and be clean, the quantity of water flowing through the filter, or, in other words, the leakage, would be usually calculated at 700 gallons per day for each square yard of surface; which, for the filter in the figure 200 feet high, would give 13½ cubic yards of leakage an hour per lineal yard of filter; an amount so small that it would flow away in a stream an inch deep, with a velocity of little over a quarter of a mile an hour. And this leakage would represent the work done by 200-feet head of water, in forcing a passage for such a stream through the obstruction presented by the filter, and imparting to it the velocity with which it issues from the lower edge.

If this prismoidal filter be supposed to be laid on its side upon an impervious soil, and the casing containing it be removed and replaced by slopes of fine sand in front and of filling in rear, care being taken to keep open a drain of dry stone, or of masonry arches, from what was previously the lowest edge of the filter (Fig. 14), the result is a bank so constructed as to fulfil the five conditions already stated for a safe bank, but without any puddle. The higher the bank for a given coarseness of sand, and

the thinner the layer of sand forming the front slope, the more water would flow through the bank; but even if the leakage increased a thousand times, and the water poured from the rear of the bank like the back lash of an Atlantic storm wave, there is no engineering difficulty in securing the rear so that the water should pass out without disturbing the outer toe of dry rubble blocks; and if these do not move, no particle in front of them can be displaced, by hypothesis, except by actual crushing of the material. It will be observed that no crack nor burrow can be made in the material of this bank, either by sun or vermin; and that it only needs its surface protecting from the action of rains and waves to form a durable bank.

In the Author's opinion, there is no other sound and safe principle on which earthen banks of tanks or reservoirs can be constructed except that described. In practice, puddle is added to stop the leakage, and the durability of the bank is thereby also increased. But a reservoir bank can hardly be considered safe if, owing to the mode of its construction, a crack, burrow, or other leak through the puddle, would be dangerous to it. In practice, the best position for the puddle is on the flattest slope in front of the bank (Fig. 10), where it should be protected by rubble, the larger and smoother the better, laid on sharp loose gravel impervious to vermin. The thickness of this protection must be so great that it cannot be wholly removed as the bank settles. Rubble packed, or very rough stone, as kunkur, is best avoided; since it will not follow the bank during settlement: hence the dry rubble facing must be thicker as the bank is higher. Unless there be liability to a scour along the inner toe, there is no occasion to make it thicker at the bottom than at the top, but rather the reverse, since the waves will be heaviest when the tank is full. The puddle will be the most dense part of the bank. Where used by the Author, the surface of puddle under construction is kept always flooded, like a rice field; and gangs of men, with their arms linked together, walk backwards and forwards on short lengths of it all day, treading it stiff to a song, as layer after layer is added by the workmen. The thickness of puddle used for banks under 40 feet high is just 1 foot thinner than that used in the bank of the Sheffield Waterworks Company, which did so much damage by bursting on the 11th of March, 1864; *i.e.*, it is 3 feet thick at the water-line, and increases at the rate of 1 foot in thickness for every 8 feet vertical depth below the water-line. The puddle must, if necessary, be carried down in a trench—sheet piling also being added if necessary—so far as to prevent any flow of water below

it being so violent as to displace material, or so copious as to be wasteful.

In order to insure the puddle remaining watertight under all circumstances of original settlement, and of alternate wet and drought, it is desirable that it should rest on a substance rather more compressible than itself. To lay it at once on ordinary rammed filling would be too violent a change; and it has always been laid by the Author on a cushion of earth moistened and rammed; each layer, of 6 inches or so, being well wetted and then sprinkled with enough dry earth to prevent it sticking to the rammer, when punned with a rammer of 40 lbs. weight. The rest of the front slope, if not already existing, has been made of earth rammed dry in the usual way; since it was found safest, indeed almost necessary, to establish the broad rule, that nothing but earth should be brought to the front of the centre line of the bank. The bank was then completed with any gravel or bad soil available, the gravel being kept at the bottom as much as possible, and the finest soil to the centre. Though such banks are not theoretically perfect, they have never failed nor given trouble upon letting the water against them. The lengths entirely constructed on these rules are insignificant, but about 5 miles of old bank have been faced with puddle laid on earth rammed moist.

The form recommended by the Author for higher banks is shown in Figs. 15, 16, and 17, which only needs a remark, that where the bank runs out on a hill-side, or the ground along the centre line of the bank rises or falls, the water which leaks through and under the puddle will be liable to run along inside the bank, instead of escaping out of the rear toe at once. Hence, at the deeper parts of the bank, larger stone is desirable at the outer toe, whatever other artifices the nature of the ground may admit of.

The greatest average monthly progress in any year made on the Soonkêsala and Cuddapah canal was 273,000 cubic yards of earthwork and 11,572 cubic yards of masonry, in the working season, April to March, 1869–1870; but this could be exceeded were labour concentrated in one spot and assisted by machinery.

The cost of earthwork varied from 2*d.* to 6*d.* per cubic yard; of rock cutting, from 6*d.* to 2*s.*; and of rubble masonry, from 5*s.* to 10*s.*, the latter including a little cut stone.

Much rubble masonry, including arch work, was done in aqueducts and bridges, as in the whole of the 9th section of the canal, at the rate of 8*s.* a cubic yard over all, with centerings found. Earthwork in black cotton soil 6 feet deep, or thrown

into banks, was done rapidly during the year 1870, at 2½*d.* a cubic yard.

The actual cost of the first 75 miles of canal—the length whose main office is to carry water for distribution below—has been £8,710 per mile, including headworks. The next 115 miles, including locks and all works, has cost £2,900 per mile; and the whole canal, including the expensive weir across the Pennêr, has cost £5,260 per mile. These rates include all English stores and plant used for the work; but to cover the cost of engineering, management, and stores in stock never issued for use, 50 per cent. requires to be added to the above figures.

The powers of irrigation possessed by the canal, as it at present exists, admit of a clear but not very precise definition, owing to the number of contingencies for which it is adapted, but which are not yet determined by experience. If rice alone be considered, the irrigating power possessed by the canal, estimated at 2 cubic yards of water an hour per acre where the waste water is lost, and 1½ cubic yard where it is again taken up by the canal below, is—

In the Toombuddra Basin	50,000 acres.
„ „ Caulee „	30,000 „
„ „ Koondêr proper	100,000 „
„ „ Pennêr „	3,300 „
Total . . .	183,300 „

To which can be added, at an expenditure of 2*s.* an acre—

In the Caulee Basin	17,000 acres.
„ „ Koondêr proper	50,000 „
Grand total . . .	250,300 „

Since the supply amply suffices for growing a second crop of wheat for every acre of rice, and it is already found that this cultivation is commencing, during the first season of the canal being opened throughout, the revenue possible at the present water rate of Rs. 6 an acre, and assuming no first crop irrigated except rice, is £300,000; and the yield, at the average yield of five years under tank irrigation in the Kurnool district, would be above 300,000 tons of rice grain, and about 500,000 tons of rice straw, and about a third of that weight of wheat and wheat straw; quantities which could be increased by the importation and use of manure. But in order to grow so much rice, the irrigation of dry

crops, such as indigo, cotton, &c., would have to be neglected; though the demand for irrigating such crops is, so far, as extensive as that for rice.

In reference to navigation, the capability of the canal seems ample; and it may be necessary to explain the reasons for this. The Board of Directors were desirous of commencing with locks of a smaller size—more like the inland locks on English canals—but at the desire of the Madras Government, expressed in 1866, this was given up. Supposing the accommodation for traffic on the canal to offer no greater attractions to the native public than that of a railway, the weekly traffic may be estimated as equal to that on the N.W. line of the Madras railway when open to Muttonpully—or say £5 per mile a week. If to this be added the immense traffic created by the canal itself, more than equal to the whole then traffic of the N.W. part of the Madras railway, the result will be as follows :—

The total population of the districts through which the canal passes is about 700,000; a population capable of consuming annually 127¾ million measures of rice if they ate nothing else. The possible yield of grain is 250 million measures of rice, and 83⅓ million measures of wheat. Supposing that 250 million measures of grain are not eaten by the local population, the only means of getting rid of them freely is by the canal, and this gives, at 3 lbs. a measure, above 300,000 tons. If this quantity be carried annually over half the length of canal, it gives a daily traffic of 500 tons a mile every working day; to this must be added straw, manure, and the commodities purchased by the sale of the product, besides all the traffic which a railway would have, as above estimated.

But a brief comparative sketch of the Madras Irrigation and Canal Company's canal between Soonkêsala and Cuddapah, and of the Grand Junction canal between Brentford on the Thames and Braunston, will give as good an impression of the work as any technical description can do.

The Grand Junction main canal is 90¼ miles long, 4½ feet deep, 36 feet broad at the top, and 24 feet broad at the bottom. The Soonkêsala canal is 190 miles long, of which 75 miles are never less than 100 feet in average breadth, nor 8 feet in depth, and average about 253 feet breadth at the top, and 9 feet in depth. The locks in the English canal are 86 feet long by 15 feet wide; in the Soonkêsala canal 120 feet by 20 feet, or nearly twice the size. The navigable branches of the Grand Junction are 28 feet, and even 20 feet broad at the water level; while the narrowest por-

tions of the Soonkêsala canal are 70 feet, or, for a few miles, 65 feet. The former has one hundred and two locks, averaging $7\frac{1}{2}$ feet rise; the latter has only forty-seven locks (reckoning double ones as two, and besides three level floored locks), averaging $9\frac{3}{4}$ feet rise. The former was commenced about 1795, and was completed as follows: 15 miles were opened up to November, 1797; $28\frac{1}{2}$ miles more were opened in June, 1798; $20\frac{1}{2}$ in 1799; $25\frac{3}{4}$ in 1800; $6\frac{1}{2}$ in October, 1800, and 3 more, including the Blisworth tunnel, in March, 1805; making, with the Paddington branch opened in 1801, a total of $102\frac{1}{4}$ miles completed in ten years, at a cost which ultimately reached about £2,000,000. The Soonkêsala canal, 190 miles long, was commenced in October, 1861, and was all brought to completion, as required by the Company's engagement with the Government, in June, 1871, or in about ten years, at a cost which, when it includes wharves and floating stock, will reach about £1,750,000. It would probably have been better had the Grand Junction canal been originally constructed of the size of the Soonkêsala canal; for, though it worked profitably to itself—so much so that its £100 shares rose to above £200—yet it proved too small to accommodate the traffic it developed, and has therefore sunk for the present under the competition of the railways. It is interesting to compare the size of the towns affected by the two canals at the time of their opening. London had then 864,845 inhabitants; Madras has about 760,000. Northampton had 7,020; Derby, 10,832; Dudley, 10,107; Walsall, 10,400; and Birmingham, 73,670. Kurnool has about 12,000; Cuddapah, 25,000; Nundial, probably 7,000 or 8,000. Again, the producing and manufacturing powers of the two districts are strikingly similar, though in contrast. The Grand Junction canal promoted the production of coal, iron, and lime from below the earth's surface, and the industrious manufacture of exotics by machinery; the Soonkêsala canal cannot but promote the production of material for food, clothing, and luxury upon the earth's surface, and the manufacture of food, cloths, colours, paper, &c., for which the Madras Presidency was formerly celebrated over the whole of Europe and Asia; and for this work the population is likely soon to be adequate.

Not only corn-fields, but also gold-fields, are far better off in a climate of prolonged settled weather and short heavy rains than in one of comparative uncertainty. It is far better for the gold-digger to have a store of water with which he can work during dry healthy weather, than to have to work in an uncertain climate where he is liable at any time to be flooded out or left dry.

It is satisfactory to find that, while the Governments in India

are becoming alive to the value of irrigation in the centre of India, those of Australia are seriously considering the same subject; and it may be hoped that the English nation will not long be behind the Hindoo, the Italian, and the Spaniard in irrigation, as they at present are.

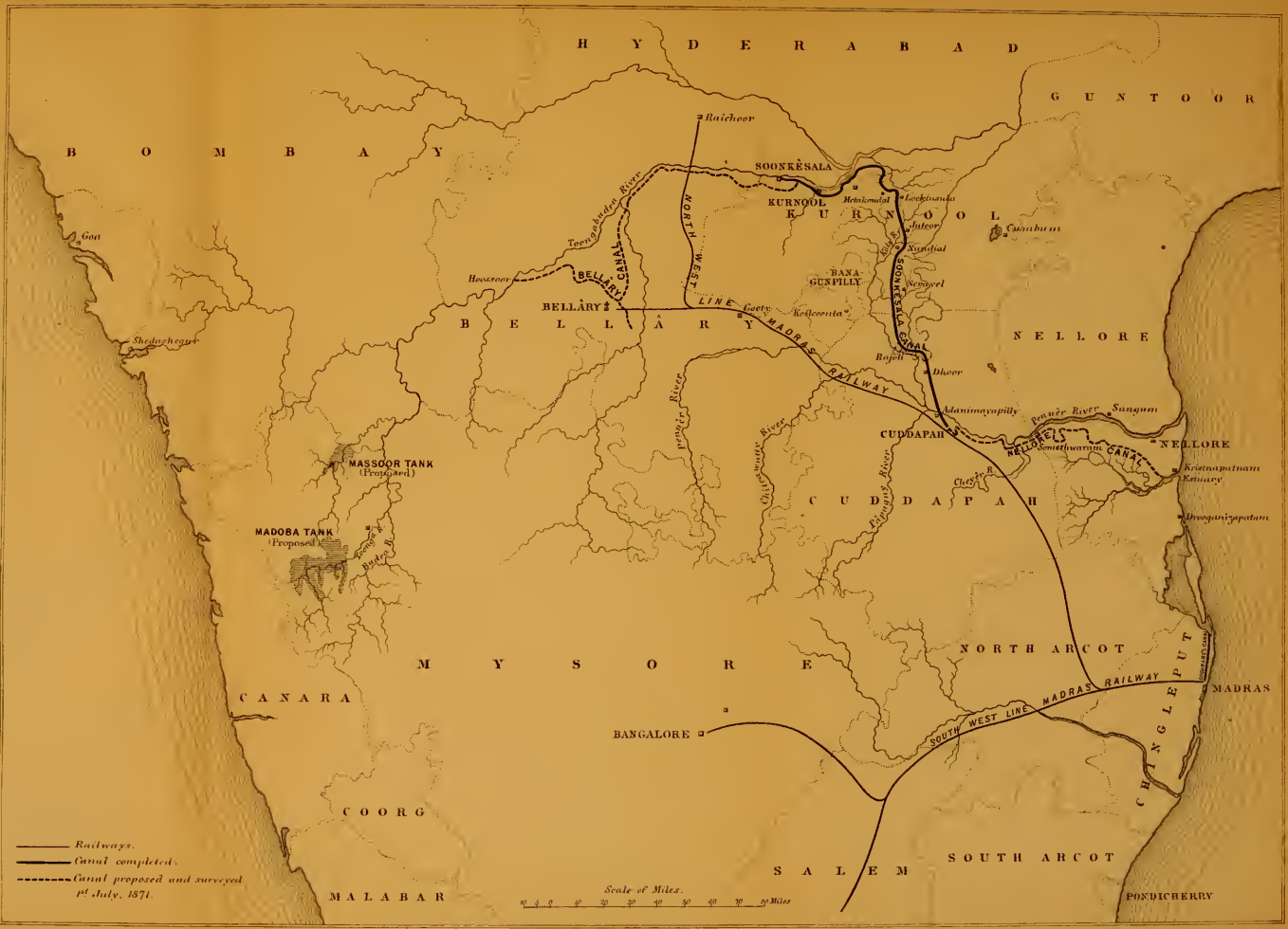
The communication is accompanied by a series of diagrams, from which Plates 14, 15, and 16 have been compiled.

[General Strachey,

THE SOONKÊSALA CANAL

MADRAS IRRIGATION AND CANAL COMPANY.

PLATE 14



J. H. LATHAM, DELT.

Minutes of Proceedings of The Institution of Civil Engineers Vol. XXXIII. Session 1871-72

KELL. BROS. LITHRS. CASTLE ST. HOLBORN

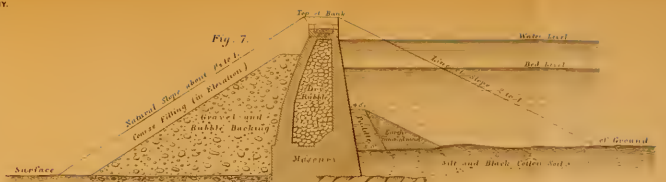
THE SOONKÊSALA CANAL

MADRAS IRRIGATION AND CANAL COMPANY.

PLATE 15

COMPLETED 1804.

SOONKÊSALA WEIR, COMPLETED 1869.



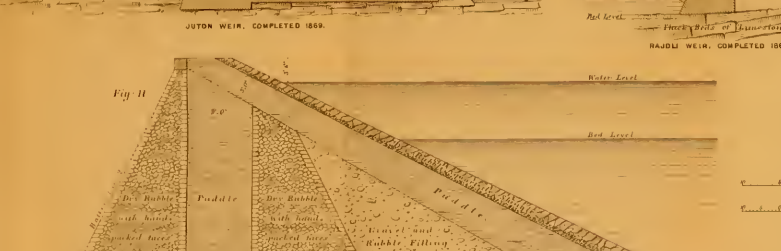
CANAL WALL, COMPLETED, EXCEPT THE PUDDLE 1866.
PUDDLE AND WING ADDED 1871.

JUTON WEIR, COMPLETED 1869.

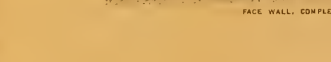
RAJOLI WEIR, COMPLETED 1869.

FACE WALL, COMPLETED 1868.

MASONRY REVETMENT, COMPLETED 1868.

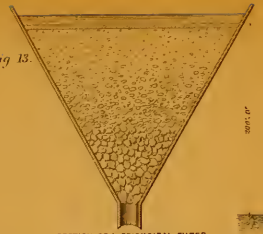


PUDDLE-CORE BANKS WITH PUDDLED FORE-SHORE ADDED, COMPLETED 1870-71.



PUDDLED BANK, COMPLETED 1868.

Fig 13.

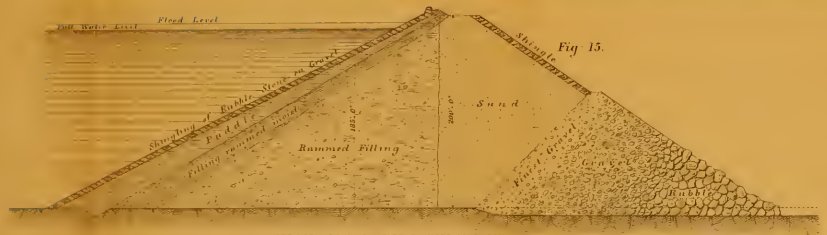


SECTION OF A PRISMOIDAL FILTER.

Fig 14.

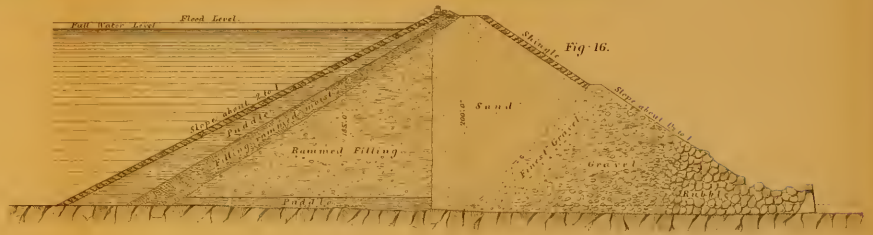
THEORETICAL BANK ON STRONG IMPERVIOUS GROUND.

Fig 15.



ORDINARY BANK ON STRONG IMPERVIOUS SOIL.

Fig 16.



BANK ON ROCK.

Fig 17.

BANK ON RIVER SAND.

General Strachey, R.E., thought the Paper was exceedingly valuable, and explained extremely well the great work on which the Author had been engaged in Southern India. His experience had been confined almost entirely to Northern India, and there was very little he could usefully say on the engineering questions which were at issue. If, in the course of the discussion, reference was made to matters not of a specially engineering nature, but touching the general subject of irrigation in India, he would make such remarks as occurred to him.

Sir A. Cotton said he had had fifty years of Indian experience, and could speak with some authority on this subject. The Soonkêsala canal was a grand work on these grounds: First, it was a large work in the upper country. Irrigation works had been executed by the Government in the deltas of the rivers and in the interior plains, but they were very different in their nature from this, which was carried through a vast, rocky, undulating country with a great fall. In the next place, it was the first instance in India of a thoroughly well-projected and well-constructed system of steamboat canal 190 miles in length. Other navigable canals of considerable extent had been constructed, and the canals of the Godavery could be navigated by steam-vessels, but these were not so complete as they ought to be. Even in America there was no steamboat canal to this day. With respect to the projection and execution of this work, he had examined all the papers that had passed between the Government and the company. It was a matter of notoriety that there was a strong prejudice on the part of officials in India against enterprises of this kind, and the papers he had seen all bore the stamp of that feeling. It was therefore quite safe to consider that in those papers any mistake in projection or execution would be brought forward, and the tone of the papers could not be mistaken. Going through them, he never was more satisfied that there was no considerable mistake either in the projection or in the execution of these works, and that they were thoroughly effective. Numerous errors were pointed out, but they were mere trifles, not affecting in the slightest degree the real, fundamental points of the work. It was a great satisfaction to him to find that it was so. The feeling was, and had always been, exceedingly strong against private enterprise in India, and every effort had been made to suppress the present company. As a rule such works got entirely into the hands of the Government; but he considered it was extremely important that these works should be entrusted to private companies, for, if any questions arose, there was no

appeal in the case of Government works. If the people thought themselves aggrieved in respect of the arrangements about water or the price, they appealed from the power which they considered treated them injuriously to that same power. They had no redress. This had been forced upon his attention repeatedly in India, because several times when he had tried to defend native rights, he had found it impossible to do so, for the authorities were the very persons they had to complain against; and he had been baffled again and again in that way. Now if a company sold the water, and the native considered himself aggrieved, of course he could appeal to the Government, and, what was more, the bias of the Government was always on the side of the native. The natives themselves were extremely sensible of this. He could not conceive what the feeling was against these works being in the hands of a company. This work now consisted of a canal 190 miles long, leading the water of the Toongabudra into the valley of the Pennêr, and by that river to the district of Nellore, where there was a vast extent of native works which had been improved by the Government, and which would receive any water that was not used on the line of the canal. The project was complete in itself in a certain sense. It would irrigate 250,000 acres of rice during the monsoon, and 750,000 acres of what was called dry-grains after the monsoon. Moreover, there were 190 miles of navigation to bring the produce down to a certain point. But two things were required in addition; first, the navigation should be completed from the end of the canal to the beginning of the Government canal at Nellore, a length of 80 miles. When that was done there would be water carriage from the head of the canal to Madras, about 400 miles. Without this the work would be in a certain sense imperfect; that was to say, at the end of the canal the produce would have to be delivered over to the railway, to be carried, at an expense it would not bear, to Madras. If, however, the water transit were completed, it would open the whole of this highly-irrigated country, not only to Madras with its 500,000 inhabitants, but also to all the markets of the world. Therefore he considered the first thing necessary to be done to complete the project was that line of water communication. The other requirement was to store water to keep the canal supplied for the five months during which the natural supply failed. Water could be stored economically all over the valleys of the Toonga and Budra, in quantities sufficient for an additional million of acres during the dry season. Those two works could be executed at prices which

would greatly increase the general return of the whole project, though the works as they now stood were, in his opinion, abundantly secure of getting a large percentage upon the outlay.

A minor point he would allude to was the cost of making these canals navigable. In this case there was a gradient of 450 feet in 190 miles, or $2\frac{1}{2}$ feet per mile, and the outlay had been £150 per foot of fall; therefore with $2\frac{1}{2}$ feet fall per mile it was £375 per mile. In considering the expense of transit works in India he would refer to the grand standard, viz., the cost of the railways in that empire. This had amounted on the average to £20,000 a mile, while the cost for lockage on this interior canal was, as he had stated, about £375 per mile—an insignificant item in comparison.

There was now open in India an unbounded field of enterprise and employment for the Civil Engineers of England, and the Madras Irrigation and Canal Company had done sensible benefit to the country in thus opening their works, and he hoped they would be permitted to complete the whole project which he had sketched out.

Even in England, where the distances were comparatively insignificant, the cost of transit was an important question; but in India it was of vital importance, where materials or produce had to be conveyed 500 or 1,000 miles to reach markets and ports. As yet almost the whole of India was shut up from the want of cheap water carriage. The railways could not properly open up India. They were carrying goods at 2*d.* per ton per mile on an average, and this only by being backed up by a heavy annual subsidy from the Government, and that charge of 2*d.* a mile was, in fact, a complete failure. India could not be developed under such a system; it must have cheap transit. He wished generally to express his opinion on this subject as an officer of long experience and a Government official. In many respects he stood in a peculiar position with regard to these works. He neither projected them, nor had he anything to do with their execution; nor was he in any way connected with the Madras Irrigation and Canal Company. He spoke as an unbiassed individual; but he could not refrain from expressing his satisfaction at seeing this extensive work completed and brought into active operation.

Irrigation works in India were now projected, and all but two or three of them were in process of execution, which would be completed at a cost of 35 millions sterling in irrigation and navigation, so that there was really an extensive work going on in this essential point.

Mr. Bateman said there could be no question as to the great importance of this work, both as a work itself, and with respect to the advantages it must confer upon India; but he confessed to being somewhat surprised at the sections of the embankments. He was himself rather an old hand at making reservoir embankments; but he must say that he dare not construct reservoir banks in the way these canal banks appeared to have been constructed. Fig. 8, Plate 15, represented an embankment 30 feet in height with a wall 2 feet thick at the top, and not more than 6 feet thick at the bottom. He could not comprehend how that bank, even with the water in the canal, could stand at all. If it did, it was a new plan of engineering, and was something from which engineers might learn, and possibly copy, for the future. He was quite sure no railway engineer, much less an hydraulic engineer, would venture to build a wall 30 feet high, 2 feet or 2 feet 6 inches thick at the top, and 6 feet or so at the bottom, and expect it to stand.

Then, as to the masonry revetment (Fig. 9), founded on sand, with no protection or provision to prevent the water from the canal passing through into the bank; that wall, judging from the scale, could not be more than about 2 feet 6 inches thick, and again he could not understand how that stood. If it did, it was a valuable piece of experience in engineering. He would like to ask the Author what was the character of the sand on which that wall stood. If it were pure sand, a depth of water upon it of 30 feet would cause it to act simply as a filter, and the water would escape. If it were argillaceous matter, mixed with sand, it might be so made as to be impermeable to water, particularly if it were made by basket labour and padded over, as on the Continent. If so made then he could suppose an embankment might be formed without puddle but impervious to water. Still the material of a bank had a particular slope at which it would stand without thrust; all above that slope would exercise a pushing force or pressure from behind, and such a revetment wall supported as shown he should scarcely expect to stand.

Again, three sections (Figs. 15, 16, and 17, Plate 16) were recommended for adoption, as the mode in which every embankment should be formed, by puddle walling on the face or slope of the embankment, without this face puddle being tied into any material at the bottom or foot of the slope. The great difficulty in constructing water-tight banks in this country was the character of the ground on which the embankment had to be formed. With the right material, and with the materials properly put together, a water-tight embankment might readily be made; but there was

great difficulty in preventing the escape of water below the embankment, through the natural ground on which it rested. If it were, though sandy, a water-tight and somewhat argillaceous mass of alluvial deposit, such as he could imagine would be found over a great portion of India, then there was not only a good material, but a material which could not, except by unskilful management, make a bad bank. If it were put together in thin layers, well trodden, it must inevitably make a water-tight mass, which would be safe. In this country where there were not such good materials, there was danger in putting puddle on the face of an embankment. The embankment, except it were made of sand, gravel, or stone, would gradually settle, the facing of puddle would crack, and the water would escape. These were his experiences; and he should be afraid to trust to less precaution than practice had taught him to adopt.

By way of illustrating how an embankment might be made perfectly safe, the Author had suggested an embankment 200 feet in height, through which the water should leak, but so as not to destroy it. Engineers usually endeavoured to construct banks water-tight in themselves, without any leakage. It was a new doctrine that embankments to be safe should be leaky, though he had known several cases of reservoirs so leaky that they were never filled, and consequently never washed away. But it did not answer to make leaky embankments. The ordinary filtering medium in this country was about 4 feet in thickness. The quantity which he understood the Author to say would filter through this embankment was 500 gallons per square yard: that would be little short of 60 gallons per square foot. He did not know in what time that would take place; but a good filter would allow 75 gallons per square foot to pass in twenty-four hours. The water to be filtered rested on fine sand, which was supported by a coarser medium of sand, and that again was supported by a coarser still, till it got to round boulders as large as turnips and potatoes. That filtration was carried on under only 1 foot or 2 feet of water pressure; or, in the case of the London Waterworks, 3 feet or 4 feet. Where the water was 200 feet deep, he should be sorry to contemplate the result in a work for which he was responsible. In making these remarks he did so only to elicit further information, as to the character of the material on which these banks were constructed, and of which they were made.

With regard to the masonry of the weirs, one of them appeared to have been placed upon red shale (Fig. 5, Plate 15). Now shale

was not a durable material with water falling vertically upon it; and unless the masonry floor was very firmly fixed, the drop of the water from a height of 14 feet 6 inches would suck out that masonry sooner than it would in that weir which was of greater height, but was placed upon the much harder gneiss rock (Fig. 3). The safety of such a work depended entirely upon the character of the rock over which the water fell. As a rule, his experience was that a perpendicular face was not a judicious form for constructing a weir, and that unless the work was built on substantial rock, the foundation was liable to be injured. A sloping weir, which allowed the water to fall gradually to the foot, was a safer mode of construction. He should be glad to hear how the sand and gravel in these banks were put together. In some valleys in Spain in which he had constructed weirs, the material consisted of sand or gravel of such an argillaceous description that it was hardly possible to make a bad bank. But if the embankment was to be formed on ground not itself water-tight, and if it had to be raised 40 or 60 feet high, it required a large amount of skill and caution to secure a good foundation.

Mr. Robert C. Reid contended that an embankment wholly of earthwork and puddled clay would make a safer and more lasting structure than a composite one of masonry and earthwork. The method proposed by the Author for constructing embankments which could leak without detriment to their stability might be theoretically correct, as far as the bank above the natural surface was concerned, but it was difficult to see how such a structure could be tied into the ground on which it stood so as to be safe. The site for such a bank must be prepared, either by excavating the whole material under the base down to an impervious stratum, and rearranging it according to the plan adopted for the portion above the surface, or a puddle trench would have to be dug and filled with clay all round the inside toe of the bank, where the finest material was placed. In order that the embankment might act as a filter-bed, the different materials must shade into each other, from fine sand to rubble, by minute gradations, or else the sand would be blown by the water through the rubble; and the process of selecting the available materials, by riddling or otherwise, and placing them in their proper positions, would be very costly. Provided the gradations were perfect, the finer the particles at the inside, the less would be the leakage, and if they were very fine, as in clay, there would be no leakage at all. There would therefore be great varieties in the retentiveness of different embankments built in this manner, and indeed in different portions of the same

embankment. It would be almost impossible to predetermine how much a given embankment would leak, and there would be no certainty of having sufficient command over the water in the reservoir, so as to regulate the supply from it.

As regarded the construction of water-tight embankments, the plan of placing the puddle wall along the inside slope was not so good, in Mr. Reid's opinion, as the vertical wall in the centre of the bank. More puddle would be required, since the area of the slope was greater than the vertical area, while the puddle trench having to be carried round the toe was longer than if it were in the centre line, and, in the event of settlement, the puddle if at the face, being inclined to the direction of subsidence, was more liable to crack than if it were in the line of subsidence, as it would be if vertical.

The proper function of the puddle wall in an embankment was to stop the 'creep' of water, which was inevitable in all earthwork unless wholly constructed of clay or other impervious material. Whenever water acted upon clay in any volume, with the slightest motion it disintegrated the particles. Now this was the condition in which the puddle would be in, if at the inner surface, with nothing but rubble and gravel between it and the water; for every wave in the reservoir would have its corresponding undulation in the water lying against the puddle wall, and would eventually in this manner eat into the clay. But, by placing the puddle wall in the centre, there was a great thickness of earth between it and the water, and the minute tubes which carried the water through the earthwork effectually retarded the action of waves in the centre, as well as prevented the direct pressure of the water on the puddle. If, however, the earthwork of the inner slope was of open, stony material, tipped in layers of 5 feet or 6 feet thick, and the stones were allowed to roll down to the bottom of each tip, it would not have the desired effect in protecting the puddle wall. Hence it was, that experienced engineers specified banks to be built in thin layers, with the most clayey portion of the material inside and next the puddle wall. On the outside slope the material next the wall should also be clayey, so that it might bear with the same effect as the inner slope on the wall, and keep it in equilibrium. The layers should also be sloped inwards to the centre, so that the beating and consolidating would tend to press the earth against the puddle wall with as great force as the water of the reservoir would when full. If the outside slope was not capable of exerting such a pressure through an infinitely small space, it could not sustain that pressure; and whenever the water rose, it would yield, the

puddle wall would bend, and, having no elasticity, would crack and cause the destruction of the bank.

There was hardly any limit to the height an embankment might be raised, as far as its power of resisting the pressure of the water was concerned; but the site on which it was built might not be able to carry the extra weight, and might bulge out above and below the bank. The slopes, which were sufficient for ordinary heights, would hardly be safe when the mass of artificial earth was increased to such an extent as was proposed.

Mr. A. J. Dodson, who had been engaged for eight years on this canal, said that, except the addition of a puddled foreshore, and the alteration of the outline of the bank in the rear of the masonry, the wall (Fig. 7), and the masonry revetment (Fig. 9), and all others of which they were types, were completed in the spring of 1865, and the puddle-core walls in the autumn of the same year. The length of canal in which the loftiest specimens of each kind occurred was opened for trial in 1866, without accident. The face walls (Fig. 8), 10,518 feet in total length, and the puddled banks (Fig. 10), were completed by Midsummer, 1868; water was passed down in July, and the canal navigated for 65 miles in August of that year, without doing them the slightest injury. A portion of ordinary bank, thrown up without selection, did, however, give way in that month.

Again, the walls represented in Fig. 7 were completed in 1865; no failure or accident occurred to these except during the extraordinary storm of August, 1870.[1] One wall in the 24th mile was then overtopped, and, as there was no protection to the bank overlying the ends of the wall, a breach occurred at the junction, carrying away about 100 feet of the bank, and something less of the wall. Another wall, in the 28th mile, of narrower section than that shown in Fig. 7, also gave way, for the length of a chain or two; and consequently all the length of the narrow section of wall—a few chains only, and no great height—had been since specially protected in the front and rear. Fig. 9 represented a masonry revetment completed in 1865, above 1 mile in length. No failure had occurred to this revetment beyond cracks, except during the storm of 1870, when it was overtopped by the water, and the bank washed away from behind, so that a breach followed 220 feet long in one place. The scour of the water towards the breach set against the toe of the revetment in another part, where

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 403.

a length of about 4 chains slipped into the canal, but no breach occurred there.

Puddle-core banks, Fig. 11, were liable to leak. One in the 30th mile, only 10 feet high, on fissured rock and gravel, had the lower part of its core washed out on the 29th of July, 1868. A puddle foreshore was then added, and no failure had since taken place. They were the least satisfactory, perhaps, of any of the sections, though they had never been breached. The banks shown in Figs. 8 and 10 had given no trouble, and they survived the storm of August, 1870.

The above mishaps were spread over a period of six years, and a distance of 65 miles. The first section was exposed to the action of river and land floods; the second, third, and fourth, to large waves on tanks, especially at Tongaduncha tank; in the fifth section land floods spread 5 miles against the upper banks 10 or 15 feet deep. It was to be remarked that the puddle was not of the best nature. It consisted of black cotton soil, which contained little clay. He thought the wonder was that with these difficulties there had not been even more accidents.

Mr. Latham had stated that 2 cubic yards per hour per acre was the datum on which his calculation of the amount of water for irrigation had been made. Colonel Cotton insisted on 1 cubic yard on the Cauvery and Colleroon irrigation works which he constructed; and Sir Arthur Cotton said that in the Tanjore and Godavery works $1\frac{1}{3}$rd cubic yard was sufficient, or 4,000 yards for the one hundred and twenty days of wet cultivation, and 1,500 cubic yards for dry crops. If that were the case the capabilities of this canal were far greater than those named in the Paper.

With regard to the navigation of the canal, the Author had stated what he imagined would be the amount of goods conveyed. That, however, would be only limited by the carrying power of the railway from Cuddapah to Madras, into which this canal now worked: but he was sure there would soon be a large amount of traffic in passengers. He had been up and down the Godavery canal, and he was astonished to see the amount of native passenger traffic from one place to another, in districts much less inhabited than those served by this canal. He confidently believed that both in an engineering and in a commercial point of view the Soonkêsala canal would prove to be a success.

Mr. G. H. Phipps observed that the particular point which interested him was, as to whether canals in India could be made to contribute largely to the means of intercommunication in that country. From the observations of Sir Arthur Cotton he appeared

to be under the impression that railways, which he assumed had cost £20,000 a mile, could not do much more for intercommunication in India than irrigation canals. Mr. Phipps thought it might be well worth while, where such a canal as the present one, costing £8,000 or £9,000 per mile, had to be constructed, to render such a canal navigable, if it could be done, as stated in the Paper, at such a moderate additional outlay as £375 per mile. He could not, however, conceive the idea of canals superseding railways as a general mode of communication over large tracts of a country like India. Although not in all cases, yet in a great many, particularly in the transport of troops and military material, speed of transit was a very necessary element, and in this instance, not only would the canal be affected by the ordinary causes of slow travelling, but this evil would be increased by the current against which the return boats would always have to contend. Assuming, however, that railways, and not canals, were to afford the means of travelling in India, the great thing was to construct them cheaper, so as to cover more ground, and thus tend to increase the trade and prosperity of the country. Their cheapness would possess the further advantage of comparatively easy renewal after being swept away by the heavy floods so fatal to such works in India. He submitted that what was wanted for India was an extensive system of railways constructed upon a cheap plan, for he never could believe that navigable irrigation canals could form an adequate means of intercommunication in that country.

Mr. Bruce said, on some of the drawings banks 50 feet high were represented as having been built on sloping ground; while on the high side he understood there was hardly any bank at all. He did not see why it was necessary to make walls of that height, if by slightly moving the direction of the canal laterally this could have been avoided. He thought Sir Arthur Cotton had injured his advocacy of canals by contrasting them with railways, because in India both railways and canals were wanted. It had been asserted that it was proposed to make an extension of this canal at the rate of £375 per mile, that the Indian railways had cost on the average £20,000 a mile, and that the latter could only carry goods at 2*d.* per ton per mile, while the canals could carry goods a great deal cheaper; and that therefore, in the proportion of £20,000 to £375, railways were worse than canals, independently of the greater cost of carriage by the former: but the fact was this very canal had cost about £9,000 a mile.

Mr. Phipps remarked that Mr. Bruce was under a mistake. It had not been stated that the canal could be made for £375 per

mile, but that that amount would render an irrigation canal navigable.

Mr. Bruce said, he understood that the extension to Nellore was to cost £375 per mile for navigation, while this canal cost nearly £9,000 per mile; but if the £375 was only to do a portion of the work of making the canal, so much the greater the unfairness of putting that in contrast with the entire cost of the railways. In the Presidency of Madras the railways had not cost £20,000 a mile, and this estimate of £375 per mile had been put against the cost of carrying the railway across the Ghâts, instead of taking the cost of the railways in the presidency, which he believed did not exceed £12,000 per mile in the case of the Madras railway, and in the Great Southern it was the same as this canal. Of course rolling stock was included in the case of the railways in that amount, not so in the canals.

Lieut.-Col. J. G. Medley, R.E., remarked on some points of detail in which this canal differed from those in the N.W. Provinces of India, that such comparisons were useful if only because the Engineers of Northern and Southern India had so little opportunity of seeing one another's works.

He should be glad to know if there were any masonry falls in the main canal, and if so, what form of fall had been fixed on? In Northern India, the vertical fall with a grating was now admitted to be the best yet devised. A cistern of water was sunk below the level of the lower bed, on to which the water fell as on an elastic cushion; while its force was also broken by its being first made to pass through a set of bars fixed obliquely in the crest of the fall, similar to the teeth of a comb. If there were no falls, the profile of the country must be very favourable, and the difficulties of navigation would be considerably lessened; but the combination of irrigation and navigation in the same canal involved difficulties which had never been successfully overcome in Upper India.

He inquired whether the under-sluices in the weirs placed across the main channel at the heads of the branch canals were found sufficient to prevent silting up? In the N. W. P. of India, regulating heads with wide sluices would be required across both channels at the points of bifurcation. He also asked whether the irrigation was all surface irrigation, or whether the water had to be lifted? And whether the water was delivered into the village water-courses from the main canal, or by intermediate distributaries? It was stated that measuring sluices were not needed. In the N. W. P. the difficulty had always been how to insure a constant discharge with a head of pressure continually varying; and

though various attempts had been made to overcome this difficulty, they had been unsuccessful, owing chiefly to the flatness of the country preventing there being any spare fall beyond what was actually required for the flow of the water. Hence the water rate was always assessed on the area irrigated, instead of on the amount of water delivered—an objectionable method, as it led to waste of water, and to continual expense in measuring irrigated areas, besides opening the door to disputes and interference with the cultivator's arrangements.

With regard to the formation of the banks, it might be noted that the great embankments by which the Ganges canal was carried for 3 miles across the Solani valley, at an elevation of from 10 to 40 feet above the bed, were formed of earth, with a double revetment of brick masonry built in steps. These had stood well, and there was no leakage. Puddled banks, without further protection, would be perforated by rats in Northern India, and there was no stone or gravel to protect the puddle by pitching: brick was the only material available.

It was estimated by Mr. Latham that 2 cubic yards of water per hour were only sufficient to irrigate 1 acre of rice. This was only $\frac{1}{4}$th of the irrigating duty now obtained from canal water under favourable circumstances in the N. W. P. when applied to wheat, the great staple of Upper India. One cubic yard per hour would there irrigate 2 acres; or, to use N. W. P. nomenclature, 1 cubic foot per second would be thought fully equal to the irrigation of 267 acres of wheat, in any canal where the irrigation was fully developed. On the Eastern Jumna canal, the most perfect in this respect in Upper India, 306 acres were irrigated in 1868-9. On the Ganges canal, where the distributaries were not yet completed, only 232 acres.

Of course the amount of water required for rice was very different from what was wanted for wheat; and although there was some rice irrigation in Upper India, it was in the autumn, when there was plenty of water available; whereas the chief crop, or wheat, was watered in the cold weather, when water was most scarce and precious. The water-rate assumed in the Paper, Rs. 6 per acre, would seem very high in Northern India, where sugar was the only crop that paid as much as Rs. 5 per acre for surface irrigation (Rs. $3\frac{1}{3}$ only if the water had to be lifted). Rice paid Rs. 3 only, and wheat Rs. 2·4. For so large a discharge at the head of the canal as 400,000 cubic yards per hour, or very nearly 3,000 cubic feet per second, the length, 190 miles, seemed very small. This was the calculated discharge of the Baree Doab

canal, which when completed would be 470 miles long; and this difference made it of little use to compare the cost of canals under such different circumstances as those of Northern and Southern India. He had roughly estimated the cost of an irrigation canal in Northern India at about Rs. 4,000 per cubic foot per second of calculated discharge, or Rs. 30,000 per mile of length. The Soonkê-sala canal had apparently cost Rs. 50,000 per mile, or Rs. 3,330 per cubic foot per second.

Mr. Bateman said, the account of the failures which had taken place afforded some confirmation of the fears he entertained from looking at the sections of the embankments. With reference to the quantity of water required for irrigation, a cubic yard of water per acre per hour was equal to a depth of $\frac{1}{6}$th of an inch of water per day. In the south of Europe, in Valencia and Murcia in Spain for instance, where there were still many of the old Moorish irrigation canals at work, the ordinary irrigation amounted to $2\frac{1}{2}$ inches in depth, renewed every fortnight in certain periods of the year, which was about the same quantity as was used in this case, if put on the land once a fortnight instead of daily; but rice required four or five times as much water as the ordinary crops of the country, and for about ten weeks of the year.

Mr. Redman observed that the remarks upon the formation of the embankments, rather confirmed the propriety of the criticisms of Mr. Aird on a previous occasion,[1] as to the absence of puddle, when it was said that the method of construction by basket-work, by men, women and children, was such as to knead the material into a very compact mass, so that it became of the nature of a puddle bank, the slope of the bank being 2 to 1. In the Bann reservoirs, County Down, the slope in some cases was 3 to 1; on an average $2\frac{1}{2}$ to 1, with a puddle bank 10 feet in thickness.[2] In 1843 Mr. Thom rather curiously advocated the disuse of puddle for reservoir embankments, and described a peculiar arrangement of the laminæ of the banks.[3] It occurred to him that the reply to the objection of Mr. Aird, that no puddle was used, viz., that the entire mass was so trodden down and consolidated as to be of the nature of puddle, might apply to some extent to the criticism of Mr. Bateman in this case.

Mr. Bateman explained that it was not the embankments he objected to, but the revetment walls, as being made too light in section.

Mr. Russell Aitken did not think any advantage had been gained

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 410.
[2] *Vide* Ibid., vol. i. (1841), p. 169; and vol. vii., p. 256.
[3] *Vide* Ibid., vol. ii. (1843), p. 191.

by a departure from the old method of constructing earthen canal embankments, viz., a core of solid retentive earth, with a puddle trench in the centre of the bank to stop any leakage. Even in England there were serious objections to facing the slopes of embankments with puddle; and in India especially it was highly dangerous, because, when the puddle was not covered by water, the heat of the sun dried it up, and caused it to crack to a great depth. In India, too, vermin were a source of great annoyance and danger, and one bank of which he had charge was perforated by land crabs. Indeed it was almost impossible to keep vermin out without masonry when the puddle was near the surface of the bank. They forced their way through the loose stones, and he had no doubt the banks of the Soonkêsala canal would one day give a good deal of trouble from this cause. True, he had while in India successfully repaired one embankment by placing a puddle apron on the face of the embankment; but in order to prevent the heat of the sun and vermin injuring the puddle, he had covered it with pitching in Portland cement, through which vermin could not penetrate. The embankment was watered once a day to prevent it cracking.

He had some time since looked over Sir Arthur Cotton's writings, and he thought that officer's views would be very well represented by the following extract from one of them: "Several lines of railway have sealed up their tract of country probably for ever against cheap transit, and even against irrigation, for the railway men, must as it were for their lives resist irrigation works in the neighbourhood of their lines, as inevitably leading to cheap transit. . . . . If the 30 millions to be spent in railways become a real warning to us, and make us consider, whether proposed works are really suited to the circumstances of India or not, they will not have been spent in vain. . . . . Every shareholder, and every person in any way committed to that dreadful mistake is now in theory at least a necessary opponent of the works that are essential to the material progress of India."[1] That opinion did not agree with the North-Western Provinces Public Works Report for 1869-70, when, without the Ganges canal and other irrigation canals, there would have been a famine. It was there laid down that the irrigation canals by producing, and the railways by carrying the produce, warded off a famine from Northern India. He believed Sir Arthur Cotton overrated the advantages of canals as a means of communication. The Ganges canal, although con-

[1] *Vide* "The Madras Irrigation and Canal Company." 8vo. Madras: Graves and Co., 1860, pp. 55 and 56.

structed for and used by barges, was almost worthless as a means of transit; nor was the revenue derived from tonnage dues of any material importance.

It was stated in the Paper that 50 per cent. of the cost of the works was spent on engineering and for unused stores. That seemed to be a very large percentage indeed, and he could only attribute it to the fact, that the money expended on these works was capital guaranteed by the Government of India. He had obtained from Mr. Fleming, who conducted the affairs of the Elphinstone Reclamation Company in Bombay, an unguaranteed work, to a successful termination, a return showing the cost of engineering during the construction of those works, from which he found that when, as in 1866, the expenditure was £350,000 for the year, the engineering cost $2\frac{1}{2}$ per cent.; afterwards it was, on £280,000, 3 per cent.; on £140,000, $6\frac{1}{4}$ per cent.; on £180,000, $4\frac{3}{4}$ per cent.; and in 1870, on £100,000, it was 7 per cent. In 1868, Mr. Aitken reported that the cost of engineering many miscellaneous works in the town and island of Bombay, aggregating several hundred thousand pounds, was 4·8 per cent. on the expenditure. In the Public Works Department, which was burdened with a number of persons who were not available for strictly engineering work, the cost of engineering was understood to be 25 or 30 per cent. on the money expended. He therefore thought some explanation on this point was due; for, even allowing £500,000 to have been expended on engineering and unused stores, there was still a sum of about £250,000 unaccounted for, and available for cost of management, &c.

If there was no error in the Paper, it condemned most effectually the guarantee system when applied to canals, which ought to be treated as remunerative works. Doubtless the guarantee system, when applied to railways, had enabled a great deal of work to be done rapidly; but railways were required for political and military purposes, and could not in India, up to this time, be considered simply as remunerative works.

Mr. R. Rawlinson, C.B., said he could not tell whether the diagrams of reservoir embankments exhibited were for instruction or for warning. If for instruction, he thought they were calculated to teach a very bad lesson; if for warning he would point out a few of their mal-arrangements. Looking at the diagrams, they seemed to represent ordinary cross sections of a waterworks impounding embankment; having slopes of 3 to 1 on the inside and of about 2 to 1 on the outside. No puddle trench was shown below the surface, nor any puddle wall in the main portion of the bank.

The outside half of the embankment was of porous material—purposely, as it seemed: the inner portion he assumed was intended to be water-tight, or, at all events, to be made water-tight when protected by puddle on the surface. He cautioned young engineers against following such an example as that; for a lining of puddle laid on the surface was most troublesome, especially if it lay on a mass of earth liable to subsidence and motion such as water-works banks would have, and especially if the material on which it rested was in any degree porous. Now, although he did not in all respects agree with the modern practice of sinking a puddle trench to a great depth (150 feet in a recent case) to get to what was supposed to be a water-tight stratum, yet he held that the practice of sinking a puddle trench to a moderate depth was one which might be safely followed; and he also held that the modern practice of constructing a puddle wall in the centre of the bank had some advantages if the puddle wall was supported by carefully-selected material, that was, by a pyramidal core of water-tight material. The tail of the outer half of the bank might then be of porous material, and even the inner foot of the bank also, the core being sound and water-tight; but to him a porous bank in the way shown on the sections, either for first construction or subsequent repair, was, in his opinion, very defective engineering, and might prove to be a very misleading, because dangerous, operation. If the inner slope was of a material not in itself water-tight, there was a method to make it so far better than by putting puddle on its surface. If, when the reservoir was being filled with water, and as the water gradually rose against the bank, a number of men were placed along the water line with flat bars or grafting tools, and were instructed to run them down well into the material, and shake them so as to wash in any loam with the water as it rose, that would make the surface non-porous to the depth the operation was carried down, and such process would be less costly than puddle; the sun would not cause cracks, nor would vermin have the same facilities for getting through it as through puddle.[1] He agreed with the Author that it was better to lay broken rubble

[1] The mass of an embankment to impound and confine water under pressure should be sound and perfectly water-tight without the aid of puddle-lining, or surface washing and warping, as described, or risk of a catastrophe would be incurred. A little care in forming a reservoir embankment is of more value than a large expenditure in subsequent repairs to patch leaks, which, as a rule, cannot be patched. The three rules in reservoir works may be thus stated—care in selecting a site, in placing the material, and in filling and subsequent working.—R. R.

on the inner slope in preference to masonry pitching. He thought masonry pitching, or wall stone, or block-in-course, formed a dangerous coating for the inner face of a waterworks bank, as the stones were liable to jam and make an arch beneath which cavities might form, and the mischief go on for a time till a failure occurred without the engineer knowing it. When a puddle trench was in rock or stable material, it was sometimes the custom to cut vertical steps. He cautioned persons who had puddle trenches to construct never to make anything of the kind, because of the liability of subsidence of the bank. If a tangent line of the subsidence was drawn, and the lines then brought down at right angles, it would be seen that the tendency would be to draw the vertical line from the upright face. Much mischief had been caused through the drawing away of the puddle from the vertical face. It was therefore expedient to let the puddle trench rest upon a slope not much dissimilar to the slope of the side of the hill where the work was. Supposing the site of the reservoir was not absolutely water-tight, instead of sinking a puddle trench 150 or 160 feet he would go down, say 30 feet, and would put a thick bed of concrete at the bottom and up the outer side, and then form drains from the outer face of concrete away from the trench into a man-hole, where the water that came through could be seen; so that if there was leakage it would be known that it was leakage through the substratum in contact with the concrete, and would come to daylight at the foot of the slope, and could be sent into the gauge basins for compensation without causing mischief to the bank. The engineer must exercise his ingenuity as to when and how he would do these things. Under any circumstances the outer half of the embankment, commencing from the puddle trench, should be perfectly drained in a way that the drains should remain permanent, so that the engineer should have the opportunity of seeing any water coming from that portion of the subsoil of the bank, and if the water did not come away muddy he might rest satisfied it was not doing his bank any harm. If after-repairs to the bank were necessary in the line of the puddle wall, he recommended engineers not to make the repairs good with puddle, supposing it was a soft bottom which caused leakage, but to use concrete.

Mr. E. A. Cowper asked how the clay was to be got into the bank? Mr. Rawlinson had suggested a means of dibbling in clay as the water rose, but he did not see how the clay was to be mixed by the grafting tool.

Mr. Rawlinson replied that clay was not necessary. Supposing there was a gravel or sand substratum to be made water-tight,

loam or soil incorporated with the gravel would make a sort of concrete and would render the bank water-tight. It was not an idea which originated with himself, but was practised by early canal engineers, as on the Bridgewater canal. He had made a service reservoir, situated on sand, perfectly water-tight by the process of washing in loam with flat bars as described.

Mr. Beardmore said he had known several banks in which no puddle was used; for instance, the North Level sea-banks were said to be chiefly composed of sand. If there was liability to rapid lowering of the water in the Soonkêsala canal the puddle slopes would be liable to slip, and in that respect a centre puddle wall was to be preferred.

Lieut.-Col. J. G. Medley, R.E., asked whether the system suggested by Mr. Rawlinson would do for running water, or did it only apply to reservoirs or still-water canals. Such puddle banks in Upper India would have to be made in some cases where there was a velocity of water of 3 or 4 miles an hour, where, as fast as the dirt was thrown down, it would be washed away.

Mr. Rawlinson said it was self-evident that during the operation the water must be comparatively still, and there must be a sufficiency of water and no more.

Mr. R. E. Forrest said, although no one had greater respect and veneration for Sir Arthur Cotton's works on India than he had, yet he thought the views put forward with regard to canals might do great damage to the cause of irrigation. It was foolish to compare canals with railways as means of transit and carriage. Irrigation was absolutely needed; but Sir A. Cotton wanted to combine navigation with irrigation. Now it was difficult to combine the two, the requirements being so different. A navigable canal required a sluggish flow of water; but for an irrigation canal the faster the current flowed the better. A high velocity saved cost and gave a better irrigating machine. The ordinary problem that presented itself was two big rivers with a tract of land between them; and the water had to be taken from one of those rivers to irrigate that tract. The best line for carrying the canal was on the ridge between the two rivers, because it then commanded the land on each side. But this central ridge was generally the poorest and least populated, and that was the reason why an irrigation canal was wanted there. All the large cities lay along the big rivers, and to carry goods canals must be made from city to city. Therefore at starting it was found the irrigation canal ran where there was no traffic; in fact, did not go near the large markets.

The slightest change in the section of a canal of the usual size in India made such a difference in the cost as to affect the whole question of the returns. For a canal, which he projected a short time since, he was told that to enable boats to stem the current the velocity must not exceed $2\frac{1}{2}$ feet per second. Supposing the current had a velocity of $3\frac{1}{2}$ feet per second, to make it navigable it would be necessary to change the whole design, and the cost would be nearly doubled. In his opinion it was preferable to keep the two questions of irrigation and navigation entirely distinct; and as food was the first necessity for the resident population, he thought it would be better to construct irrigation canals at once, leaving the consideration of the facilities to be provided for its transport to more distant localities, whether by navigable canals or otherwise, to be dealt with hereafter.

The system of canals in India was not generally understood, but it was very simple. The canal started from a big river to irrigate a tract of land, with the water running at as high a velocity as the bed would stand. It was necessary to design the canal to carry 3,000 cubic feet of water per second in the monsoons, and only about 1,800 feet in the winter season. When in addition arrangements for navigation had to be made, it swelled the cost to such an extent as to make the returns almost problematical. He spoke from experience of some large canals which had been projected by European engineers. Without the arrangements for navigation, such as locks and still-water reaches, and as irrigation canals alone, they were calculated to give a return of 8 or 9 per cent., but when arranged for navigation it would be rather difficult to make them pay 4 per cent.

Considering that it was so difficult to get money for irrigation works, that in India there was a disinclination to raise more money by additional taxation, and that railways were better adapted for carrying than any other means of conveyance, he thought it would be better to make the irrigation canals, and to leave the navigation alone.

Mr. J. H. Latham, in reply upon the discussion, said, with regard to the face walls, Fig. 8, that there were 5-feet counterforts, 16 feet apart, from centre to centre, on the water side of the wall. Considered as a retaining wall, it was stronger than many to the west and south of London, but not so strong as would be built were the sleepers of the permanent way laid close behind the coping. The gravel was not water-worn, but quartz split into irregular crystals, and was much rougher than water-worn gravel.

The masonry revetment, Fig. 9, was not lying on clear sand, as

had been supposed; it was silty river sand, and a section would stand vertically 12 feet high when dry; but water would percolate through it. The puddle at the toe ran across the whole of the canal bed, and so made it water-tight, and prevented any percolation. In the flood of August, 1870, when 12 inches of rain fell in twelve hours, the water topped the masonry revetment, and it was then not a question whether the wall was a sound one or not, for the sandy bank behind must have been washed away. The revetment wall, which was not a self-supporting wall, but rested upon the bank, of course failed; but the face-wall (Fig. 8) had never suffered.

The Soonkêsala anicut (Fig. 4) was generally upon solid gneiss, and occasionally trap; but hitherto there had been no danger from the rock being carried away. The Rajôli anicut (Fig. 6) was upon limestone, about 10 inches thick in the bed; and though limestone was a treacherous formation when beds of dirt lay between the strata of stone, in this case the stone was solid, and, as the fall was not great, it was uninjured. The Jutoor anicut (Fig. 5) was in a part of the river that contracted below the weir, and consequently, before there was much water flowing over, the crest of the weir was almost 'drowned.' The fact that the water-cushion had not suffered therefore proved little. Indeed, the spoil, or rocky deposit of the river, rose in rear of the water-cushion, and when the water ceased flowing over the weir the standing water almost concealed the crest of the lower wall of the water-cushion. Nothing with regard to water-cushions could be learnt from that. He supposed, from the fact of the face-wall (Fig. 8) not having given way under the great flood,[1] that the work was good. Great care was taken with it, and it was built under close supervision and inspection over very short lengths at a time.

As to the imaginary sections, he considered it an advantage to have puddle in front, where it could be got at, not quite on the slope, but protected in front. Care had to be taken of the quality of the puddle. If it was liable to run it could be put farther into the bank, and a greater weight of gravel and shingle laid in front to hold it up. But the puddle was not the only protection; it lay upon earth; and a sun-crack running through the puddle would not be liable to run continuously into the earth, which was not homogeneous with it. Even if leakage existed, the bank might

[1] When a portion of the old wall gave way, as Mr. Dodson described, under the flood of August, 1870, the water was suddenly lowered in the canal in front of the face-wall; but the face-wall stood that test without any cracking or failure.—J. H. L.

theoretically be constructed so as to be secure, as in Fig. 14. In practice such a delicate arrangement of stone and sand would be difficult to obtain, but with puddle in front the leakage was so small that such refined selection was not necessary. In cases of rock foundation, or of irregular foundations of different kinds of strata, the subject was too wide to enter upon. But he had shown a puddle trench, with sheet piling in the centre (Fig. 17); the object being to throw down the leakage, so that whatever there should be must flow out clear of the bank, without any tendency to scour or remove the material of the bank itself, or the material on which the rear of the bank rested.

The relative merits of railways and canals in America and India were very different. In the former case railways had been used for opening out the country; but in India canals were more suitable. In America every man understood a good deal about the repairs of railways. In almost every hamlet the first thing erected was a sawmill, and in the larger towns wooden lattice girders could be bought ready for use. In India the people knew little or nothing about railways; but they did understand irrigation. In every village there were a number of woddahs, or native navigators, and in every district a large expenditure was incurred annually in repairing tanks, wells, &c. While in America the country was opened out by railways before it was inhabited, in India the first thing was to provide some means of irrigation, if it were only by wells: but after the country had been opened out by canals, railways would be necessary for developing trade. He believed that if a tract of country were opened out by a canal it would often be found the cheapest means of commencing a traffic to make that canal navigable; and he thought that this course had been wisely pursued in the canal under discussion. It had a series of up-takes from different rivers; and consequently never got so far from the large towns, which were generally near the river side, as the Ganges canal. It was the reverse in another point: the Ganges main canal had a fall of about 18 inches a mile, and the distributing channels less fall; and thus, when the distributing channels were full, there was a current of 3 miles an hour: whereas in the Soonkêsala canal the usual fall was 6 inches and under; that of the channels was 2, 4, or 6 feet a mile; and there was scarcely a mile and a half in any portion where the current at all approached the velocity of 3 miles an hour. In the Soonkêsala canal the chief supply of water for irrigation was taken off from the canal just above the first drop-lock in each branch; so that if irrigation

were in full action, the navigation down to the locks, and of course in the ponds between the locks, must be complete. This was not the case in the Ganges canal. The banks of the canal almost necessarily ran across some rather deep hollows. An investigation was made of the relative cost, and additional length, of running round some of the valleys instead of across them, and the balance was struck. In one case, where the circuit of the valley was made, 1 mile was thereby lengthened into 3 miles. In other cases the ratio of increase would be greater, so that it was best to carry the canal across these valleys. There were no masonry falls in the canal, and the scouring action of the under sluices in the weirs was local. In more recent works the head sluice was at right angles to, and close upon, the under sluice, the latter being 3 feet lower, so that the scour took place across the whole face of the head sluice. The sand in the Soonkêsala anicut for almost the whole length lay within about 18 inches of the crest.

No attempt had been made to deliver water by measurement; and though he had taken 2 cubic yards per hour from the Madras Government as the datum on which to calculate the capacity of irrigation, he had no more faith in that than he had in the previous Madras practice as regarded provision for drainage, which turned out fallacious. There had been no experiments to indicate how much water per hour per acre was required in that part of India. In the consideration of works of irrigation in Jamaica in 1871, the Surveyor-General of Jamaica, after careful inquiry, adopted 1 cubic yard of water per hour for rice irrigation; he imagined that was enough for a rice crop, and that 2 cubic yards an hour would be too much.

The cost of the engineering staff on these works included that of the surveys for the Nellore part of the works, the Bellary scheme, and the reservoirs; also stores sufficient for executing the whole of these works; so that it was an exceptionally large percentage. But there were no contractors; the engineers themselves did the work which was usually done by contractors; and he did not think engineers would be content to carry out works of this kind at 4 or 5 per cent., including the cost of all the subordinate staff, and of both Home and Indian establishments.

March 19, 1872.

T. HAWKSLEY, President,
in the Chair.

No. 1,328.—"On the Conditions which favour, and those which limit, the Economy of Fuel in the Blast Furnace for Smelting Iron."[1] By Isaac Lowthian Bell, Assoc. Inst. C.E.

During the last Session a Paper by Mr. B. Samuelson, M.P., was read, in which an account was given of two blast furnaces erected near Middlesbrough, justly stated to embrace all the recent improvements in a plant of this description.[2] The value of that communication was enhanced, by the details of the amount and quality of the duty these furnaces were capable of performing, and of their working results compared with others of a less perfect character of construction. This led to a discussion on the conditions most favourable for securing the utmost economy of fuel, which conditions, according to the views expressed by the Author of the present Paper, were of a nature to impose a limit, beyond which it is useless to expect any further reduction in the quantity of combustible burnt in the furnace itself, to produce a given weight of pig iron. The Author then maintained that, after certain dimensions of a furnace were attained, no further advantage from subsequent enlargement was possible, so far as fuel consumption was concerned. This opinion is based on there being, according to his views, an actual evolution of heat near the throat of the furnace, which maintains a tolerable constancy of temperature in the escaping gases; and also that, as soon as sufficient time had been afforded to permit the requisite saturation of these gases with oxygen, no good could arise from their further retention among the materials. This latter condition likewise involves the useful limit to high temperature in the blast, for it will hereafter be shown, that any increase of energy in the reducing power of the gases, acquired by a greater intensity of heat, is neutralised by a corresponding loss of fuel.

In opposition to these views it was alleged that no such heat

[1] The discussion upon this Paper occupied portions of two meetings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 329.

evolution as had been referred to took place in the upper zone; that there existed no limit whatever to a useful increase in the temperature of the blast; and that furnaces might still be profitably enlarged, provided some modification of form was introduced.

The subject of economising fuel in a process consuming nearly one-sixth of all the coal raised in the empire justly excited much interest upon the reading of Mr. Samuelson's Paper; and as this branch of the question only came up incidentally upon the occasion referred to, the Author ventures to submit to the Institution the present communication, which deals exclusively with the working of the apparatus then so fully described. In it the principle of the blast furnace will be exposed for examination, along with the reasons for concluding which of the two sets of antagonistic opinions are most in accordance with the nature of the operation.

Were an engineer requested to furnish a design for any particular structure, his first demand would be to ascertain the nature and amount of strain the edifice would have to sustain; and then, with his previous knowledge of the strength of materials, he would calculate the dimensions of its various parts.

Such ought also to be the conduct of the scientific metallurgist, when he approaches the inquiry of fuel consumption in the production of pig iron. He must first satisfy himself in respect to the quantity of heat absorbed in the process, and then, by estimating the calorific power of the fuel, he must determine the weight of combustible necessary to afford the required effect.

The heat absorption in smelting iron must be the sum of the different steps in the process, in respect to some of which there may be a little doubt as to the exact value of their respective coefficients. There are also among the steps themselves some which, in certain cases, vary considerably in amount. Thus a rich ore needing a small quantity of flux presents a smaller weight of slag to fuse and limestone to decompose than one of a poorer description. This very variation, however, affords a means of checking the general correctness of the estimate, for by eliminating the variables there remains, what the Author has designated on another occasion, the constant heat requirement of iron smelting, which, under circumstances of great dissimilarity, has run out at the same figure, justifying the belief that a very close approximation to truth has been attained.

As regards the heat evolution, this in the case of coke depends upon the quantity of carbon it contains; but, as is well understood, carbon is capable of two distinct degrees of oxidation or

combustion. It may be burnt to carbonic oxide, and it may be burnt to carbonic acid, the latter containing two equivalents, or double the quantity of oxygen found, combined with carbon, in the former. Different authorities are so nearly agreed upon the quantity of heat evolved by the generation of each of these compounds of carbon and oxygen that, in even numbers, when a unit of carbon is converted into carbonic oxide, it may be assumed there is an evolution of 2,400 heat units, centigrade scale, against 8,000 when carbonic acid is the product of combustion.

It will be seen hereafter, that the real difficulty in the calculation does not consist in ascertaining the actual quantity of heat necessary for the process, but in determining what proportion of the fuel can be burnt to that condition where 8,000 heat units and that where only 2,400 are the products of its combustion.

Assuming that the ore yields 40 per cent. of pig iron, and requires 15 cwt. of limestone as a flux, the following table exhibits in even numbers the heat absorption per ton of metal :—

	Centigr. Cwt. Heat units.	
No. 1. *In the zone of fusion :*		
Fusion of iron	6,600	
„ slag	17,000	
Decomposition of atmospheric water . . .	2,800	
„ of phosphoric, sulphuric, and silicic acids	4,000	
Absorbed by expansion of blast, &c. . . .	4,050	
Transmission through walls	450	
		34,900
No. 2. *In the zone of heat interception :*		
Transmission through walls		2,500
No. 3. *In the zone of limestone decomposition :*		
Expulsion of carbonic acid from limestone .	5,550	
Decomposition of „ „ . .	5,760	
		11,310
No. 4. *In the zone of reduction and carbon impregnation :*		
Reduction of peroxide of iron to metallic state	33,100	
Carbon impregnation	1,440	
Evaporation of water in coke	300	
Transmission through walls	650	
		35,490
No. 5. *Loss in the escaping gases*		8,800
		93,000

In the appropriation of heat just given, the furnace is regarded as consisting of four divisions, to which must be added a fifth head expressive of the quantity carried off in the escaping gases.

No. 1. *The zone of fusion* is comprised in the lower part of the furnace, in which mere liquefaction, by high temperature, is effected,

or where there is chemical action, it is of that order to require for its accomplishment that the materials should be melted. The heat absorbed in this region is set down at 34,900 units.

No. 2. *The zone of heat interception.*—Several analyses of the gases, collected at various depths of furnaces, have led the Author to conclude that, for economical working, a very large proportion of their cubic capacity ought to be devoted exclusively to the interception of the heat carried away from the zone of fusion, by the rapid current of gas proceeding from that region. It was estimated, by careful observations upon two occasions of blowing in a furnace, that the actual heat evolved at any one time in the zone of fusion, by the combustion of the coke, was augmented by 70 per cent. from that absorbed by the materials during their progress downwards. Regarding this division as one of interception alone, no demand is made on the heat resources of the process, save that arising from transmission through the walls, which has been calculated to amount to 2,500 units.

No. 3. *The zone of limestone decomposition.*—As soon as the flux arrives at a depth from the top of the furnace, where the temperature is sufficiently elevated to cause its carbonic acid to part from the lime, decomposition takes place, and along with it an absorption, in the case under consideration, of 5,550 heat units. The carbonic acid thus liberated is, in its turn, decomposed by the highly incandescent carbon it meets, causing a further absorption of 5,760 units, and at the same time a quantity of carbon of the fuel is dissolved, which, never reaching the tuyeres, is the source of a further loss in a heat-producing point of view. The weight of carbon carried off from the coke is equal to that contained in the carbonic acid decomposed in the manner described, and which, for 15 cwt. of limestone, is 1·8 cwt. per ton of iron.

No. 4. *The zone of reduction and carbon impregnation.*—In the Author's opinion much misapprehension has hitherto existed, in respect to the temperature required for separating the combined oxygen from the metal in an ore of iron. Instead of a great heat being necessary for this operation, it is one which commences at 400° Fahr. (205° C.), and is so speedily effected, that before the oxide of iron has arrived at a point where the heat is full red (1,000° to 1,200° Fahr.) reduction may be regarded practically as completed. This happens before the ore has descended 15 or 20 feet in the furnace. Simultaneous with reduction is the carbon-impregnation already alluded to. The total quantity of heat absorbed in this zone, by the great amount of chemical action effected within its limits, is estimated at 34,540 units. Inasmuch, however, as the

carbonic oxide which performs these two changes is itself converted into carbonic acid, there is a heat evolution which frequently amounts to 36,800 units, so that there is generated heat enough not only to meet the absorption consequent upon reduction and carbon-impregnation, but also to cover the other requirements proper to this zone, and leave a small balance, about 1,300 units, in excess, the total absorption being taken at 35,490 heat units against 36,800 evolved.

The process spoken of as carbon-impregnation is a very peculiar one. When carbonic oxide is brought in contact with oxide of iron at temperatures short of full red, it is split up into carbon and carbonic acid. This the Author, from recent observation, is of opinion goes on to a very large extent, so that the ore in the higher region of the furnace, by the copious deposition of carbon in its pores, breaks down into a state of coarse powder.

No. 5. *Loss in the escaping gases.*—In a furnace of sufficient magnitude this has been estimated to be represented by 8,800 units.

This mode of dividing the interior of a blast furnace is, no doubt, very convenient for describing the process of iron smelting; but it must not be supposed that any lines could be laid down defining the exact position of the zones themselves, or that each division is performing its own functions and no other. With the exception of an extremely minute space in the zone of fusion, heat is being absorbed from the ascending gases, not only by the solids but also by the iron and slag in the act of their being melted. The second division, viz., that of heat interception, more than any other, has its duty limited to that indicated by its name; but even here there are occasional disturbances due to chemical action. In the zone of limestone decomposition, the temperature required for splitting up the flux is almost entirely derived from the gases still retaining a large quantity of the heat they absorbed at the tuyeres, and the same may be said of that part of the furnace in which reduction and carbon-impregnation take place, for a considerable portion of the materials filling it are red-hot, due almost entirely to the same cause. Thus the two upper regions are also, to a large extent, zones in which heat is intercepted. Moreover, it is quite possible that, in certain localities, reduction of oxide of iron and decomposition of limestone may be going on side by side, zone No. 3 performing part of the function considered to be the peculiar province of zone No. 4.

To ascertain the actual quantity of coke required to produce a ton of iron under the circumstances described, there must be deducted, from the total number of heat units absorbed, those otherwise derived than from the combustion of the fuel.

Total cwt. heat units as per absorption account required per ton of iron		93,000
Less heat evolved by conversion of carbonic oxide into carbonic acid	36,800	
Less heat in compressed air, say	1,200	
		38,000
Leaving to be supplied by coke		55,000

Now 55,000 cwt. heat units divided by 2,400 gives their equivalent in pure carbon . .	=	22·9 cwt.
To which add carbon absorbed by iron . . .		·6
Total pure carbon		23·5 cwt.

which is equal to about 25½ cwt. of ordinary Durham coke.

It requires but a moderate acquaintance with the simpler laws of heat and chemical action to realise some of the conditions which regulate the action of the blast furnace.

In the lowest zone, the act of fusion and its accompanying decompositions may be said, as a matter of speed, to be regulated by the rapidity with which the carbon is oxidized, and this for all practical purposes is settled by the rate at which the blast is injected at the tuyeres.

It is widely different with the interception of heat, which requires time for its accomplishment; hence, if the furnace is too low, the ascending gases will not have time to communicate their sensible heat to the descending solids, and the latter will, in consequence, arrive at so low a temperature at the tuyeres as to demand an addition to the fuel which has to liquefy the metal and slag. Precisely the same argument is applicable to the upper regions, in which the principal part of the chemical action of the smelting process is carried on.

These considerations involve the question of the height of the blast furnace and the quantity of work it is capable of performing. The dimensions which will enable an iron smelter to produce a ton of metal with 25½ cwt. of coke burnt with cold blast, from ordinary clay ironstone, are at present to some extent a matter of speculation; but at Lilleshall, foundry iron is obtained at an expenditure of 27½ cwt. with cold air, from the ordinary ironstone of the coal measures, yielding a trifle above 40 per cent. Whatever height and capacity may be needed for proper working, the object to be attained is, as the fuel is consumed in the hearth which has to provide the heat requirements of the furnace, that the carbonic oxide generated by the

combustion must be retained a sufficiently long time in contact with the materials to absorb all the oxygen it is capable of holding, and the ascending gases before they quit the throat must part with all the heat of which they can divest themselves.

Furnaces able to produce a ton of pig-iron, under the circumstances described, with from 27 to 28 cwt. of coke, have not been in use more than nine years, prior to which they rarely exceeded 50 feet in height, with a capacity of 6,000 or 7,000 cubic feet. In those at Lilleshall, with the same minerals now employed, the ordinary consumption of fuel was 40 cwt. instead of $27\frac{1}{2}$ cwt. It may be instructive to consider the nature of the change of action which will suffice to account for so marked an economy in the quantity of combustible required to produce the same result. To assist in this examination, it will be necessary to keep in view a few of the facts connected with the action of the oxides of carbon on the iron oxides, as well as on the metal itself.

When a stream of carbonic oxide is passed over oxide of iron (Fe_2O_3) at a temperature moderately elevated (400° to 1,200° Fahr.), the metal is reduced to its metallic state, and the carbonic oxide becomes carbonic acid. Under one condition of things, therefore, carbonic oxide can split up the oxide of iron; but, it is important to remember that, under another the newly formed metal can in its turn take back a portion, at least, of the oxygen from the carbonic acid generated during the process of reduction.

In the blast furnace this antagonistic reaction has to be kept in check, by the presence of a certain quantity of free carbonic oxide, and as the extent to which this is necessary has an important bearing on the question, the Author has made it the subject of a lengthened experimental research, which has been fully described elsewhere.[1]

It must also be remarked, that the positions of equilibrium, in which certain mixtures of the two compounds of carbon and oxygen are inert upon different oxides of iron, vary considerably, according to the temperature at which they are brought into contact with each other.

To exhibit this, recourse is had to a diagram (page 118) in which the different elements involved in the action are represented by somewhat arbitrary combinations of letters.

In Fig. I. an equivalent of peroxide of iron is supposed to be

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[1] *Vide* "The Journal of the Iron and Steel Institute,' vol. i., p. 85, "Chemical Phenomena of Iron-smelting."

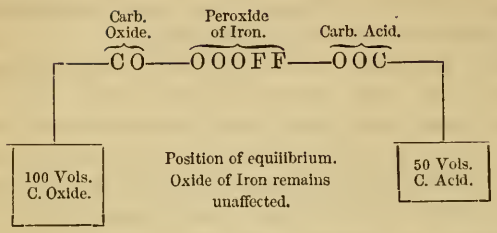

FIG. I. Temperature 300° C., being that of escaping gases.

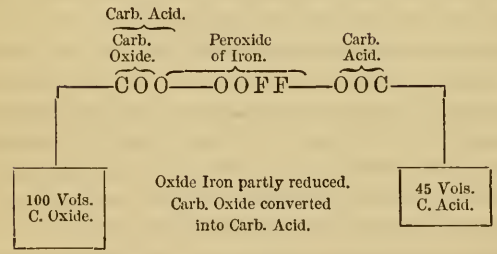

FIG. II. Temperature, 300° C., being that of escaping gases.

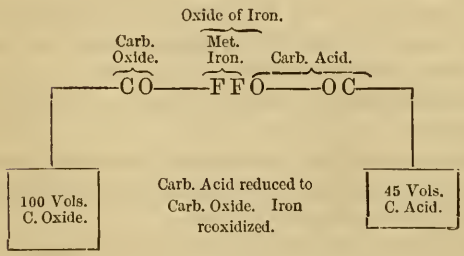

FIG. III. Temperature, red heat.

surrounded by an atmosphere of the two oxides of carbon in which the carbonic acid is half the volume of that of the carbonic oxide. In this case the oxidizing tendency of the higher carbon oxide is equal to the reducing tendency of the lower, and in consequence the peroxide of iron remains unaffected at the usual temperature of the escaping gases.

In Fig. II. the oxidizing tendency of the carbonic acid is diminished by reducing its quantity to 45 volumes, the other gas remaining unaltered. In this case a portion of the oxygen has gone over to a portion of the carbonic oxide, which it converts into carbonic acid.

In Fig. III. the metallic iron just reduced from the oxide is immersed in a similar mixture to that in Fig. II., but the temperature being raised, a portion of the oxygen of the carbonic acid has reoxidized the metal.

There is another series of reactions which plays an important rôle in the subject under consideration, not as preventing reduction of the ore, but as being the cause of a waste of heat and, in consequence, of fuel.

At a high temperature carbonic acid is split up by carbon, and by the action one equivalent of the acid becomes two of carbonic oxide. This unburning, as it were, of carbonic acid causes a loss of 5,600 heat units for each unit of carbon so treated, and as a similar quantity of carbon is carried off, and is thus prevented furnishing its quota of heat at the tuyeres, there is a further loss of 2,400 heat units, in all 8,000 units, to be deducted from the amount, were this secondary action avoided.

The mode of avoiding the loss from this decomposition of the carbonic acid, generated by the reduction of the oxide of iron, is to secure the latter operation being performed under circumstances where the temperature is elevated enough to deoxidize the ore, but not sufficiently intense to have the resulting carbonic acid split up by carbon. This is secured by removing the region in which reduction, and also carbon-impregnation, takes place, to a sufficient distance from the zone in which the materials are too intensely heated by the ascending gases. This will be best understood by a reference to Plate 17, in which it is supposed that the ore has been long enough exposed to suitable temperatures to have lost all its oxygen. In the lesser furnace, before this expulsion of oxygen has been effected, the ore is supposed to have reached a point where the temperature is so elevated that a portion of the carbonic acid is resolved into carbonic oxide.

The proximity of the throat of the furnace to a region of intense temperature is further productive of loss, by the gases escaping still charged with an excessive quantity of sensible heat.

If, instead of these gases containing say 6½ cwt. of carbon as carbonic acid, 2½ cwt. had been brought back to the position of carbonic oxide, and instead of 8,800 heat units being found in the gases there was double the quantity, this loss would amount to

2·5 cwt. carbon, less as carbonic acid : 2·5 × 5600 =	14,000	heat units.
2·5 „ „ less to burn at tuyere : 2·5 × 2400 =	6,000	„
Additional heat in gases	8,800	„
	28,800	„

This number of heat units is equal to 12 cwt. of carbon, or fully the difference of coke found to be economized at Lilleshall, per ton of iron, by the use of the larger furnace.

The position of what may be designated a perfect form of furnace has thus far been considered, without reference to the progress of events, or the order of improvement which led to its adoption. It was not so, however, in the year 1827, when a height of furnace of 50 feet, and a capacity of from 4,000 to 6,000 cubic feet, fulfilled all the requirements deemed necessary by the iron smelter.

About the year in question, a manager of a gas-works, Mr. J. B. Neilson, M. Inst. C.E., conceived the idea that, by heating the air before it entered the blast furnace, an increased intensity of temperature would ensue. The conception formed the subject of a patent, since so extensively known as that of the "hot blast," and which, at the period of its introduction, constituted one of the most remarkable events in the history of the iron trade.

It cannot be denied, that Neilson was justified in the inference he drew, with regard to a change of intensity of temperature, by the previous heating of the air used in burning the fuel; but, admitting this, there does not appear on the face of it any reason for expecting that a certain quantity of heat imparted to the blast should be capable of performing more duty, than a similar amount of heat evolved by the combustion of the fuel consumed in the furnace. Thus, if 2,400 heat units were generated by burning one unit of carbon on the hearth with air at 0° C. (32° Fahr.), on adding 400 heat units to the blast, carbon sufficient to produce 2,000 heat units would have been able to do the same amount of work as 2,400 units evolved by the union of carbon and cold air; and thus a saving of about 16 per cent. in the furnace fuel would have ensued,

obtained, however, by a corresponding expenditure in heating the air.

Had this been the extent of the saving—and it certainly was all Neilson, at the time, was justified in anticipating,—the project which wrought so complete a revolution in the manufacture of iron must inevitably, from the difficulties attending its introduction, have proved a commercial failure. The apparatus for heating the air is costly; it imposes, from increased friction, greater work on the blowing engine, and it entails a certain expense for maintenance. To these disadvantages must be added the ascertained fact—apparently overlooked by Neilson—that of the heat evolved in the hot-air stoves only one half finds its way into the blast furnace, the remainder being lost at the chimney, by radiation, &c.

Notwithstanding a loss of calorific power in heating the air, in Scotland, where the hot blast was first put into practice, it was soon ascertained, that for every cwt. of fuel consumed in the stoves, fully 4 cwt. were saved in the furnace itself.

This apparently mysterious action was set down, in Neilson's time, to the expected increase in the intensity of the temperature in the hearth, a mode of explanation which, more or less, has been adopted by all subsequent writers on the subject; and during the discussion upon Mr. Samuelson's Paper, Mr. Bramwell expressed himself as opposed to the belief, that the heat in the crucible of a cold-blast furnace was as high as that in one blown with hot air.

The Author will briefly give his reasons for dissenting from the views expressed by Mr. Bramwell, and for believing that the explanation mentioned above, as accounting for the economy of fuel effected by heating the blast, is entirely erroneous.

It may be premised that the alleged increase of actual intensity of temperature in the hearth of a hot-blast furnace is purely speculative, for there are no instruments capable of measuring it with exactness. The duty performed in the crucible of a blast furnace represents, of course, the manner in which the heat evolved there is disposed of; and hence, if the amount of this duty is increased, as it is when the same weight of fuel has more iron and slag to melt, it by no means follows, that although the fuel when burnt with heated air affords a more intense temperature, the actual intensity may, by the increase of duty, be reduced to what it was when cold air was employed.

The following reasoning and experiment induce the Author to conclude that the last-named supposition is the correct one. All iron smelters are agreed that, to obtain the 'richer' or greyer qualities of iron, the furnace must be worked hotter than when

'poorer' qualities are sought for. It has been considered that chemical differences in the composition of the metal were the cause of this; but a large number of analyses have satisfied the Author that there is no real foundation for this belief, and that the real cause of change of quality is entirely one of temperature. In illustration, specimens are exhibited of grey iron produced by melting white pig metal in the current of hot slag as it flowed from a furnace making foundry iron. It may be added, that samples of iron, before and after this change, have been proved to exhibit no alteration in their chemical composition.

Before attempting to point out what the Author believes to afford the true explanation of the theory of the action of the hot blast, he would call attention to one or two circumstances in connection with its application which, in his opinion, have been too little considered by those who have examined the subject.

In treating Scotch black-band, for every ton of iron made there was produced about half a ton of slag; so that in the hearth there had to be fused 30 cwt. of material, effected, in the days of cold blast, with 60 cwt. of coke.

In Wales, and in some parts of England, the weight of slag was about 30 cwt. to the ton of iron, giving thus 50 cwt. to be melted at the tuyeres; and yet this was done by means of cold air with 40 cwt. of coke.

In France, M. Dufrénoy, who was sent over in 1834 by his government to report on the use of the hot blast, mentions a case where 20 cwt. of iron and 30 cwt. of slag were fused with 25 cwt. of fuel, the air used being cold.

Equally disregarded, as a matter of argument, has been the great difference of effect produced by the application of hot blast in the three instances just quoted.

In Scotland raw coal took the place of coke; but there is little doubt, were coke still employed, 30 cwt. would be amply sufficient with hot blast to do the work of 60 cwt. when cold air was used, giving 30 cwt. as the saving of furnace fuel.

In England and Wales, for the cases given, 10 to 12 cwt. of coke was all the economy realised by the change from cold to hot air; and in France, upon the occasion alluded to by M. Dufrénoy, the saving, if any, was so inappreciable, that he reported the results there to be "unfavourable to the use of hot air."

One author, in arguing in favour of an increase of heat intensity, mentions that if 1000° C. were required to melt a substance, 999° C. might be applied for ever, without fusion being accomplished. There is no proof, however, that there is any marked

difference between the melting points of different brands of iron; and the Author has satisfied himself, experimentally, that slags from the black-band of Scotland are as easily fused as those from the clay-ironstone of England. Under these circumstances, the supposition that heat intensity in the hearth is greatly concerned in the economy of fuel, seems utterly untenable, particularly when it is remembered, in the instances quoted, that the larger the quantity of matter which is fused in that zone, for a given quantity of fuel, the less is the saving by the use of hot air.

The law which, the Author believes, determines the weight of fuel required to smelt ores of different kinds, and which constitutes the value of the hot blast, is, that the rate of reduction should not proceed less rapidly than that of fusion.

When a furnace is driven with cold air and is of inadequate height, it has been shown that there is a loss of fuel; and this was explained by the fact, that the reducing gases escaped before they had absorbed all the oxygen they were capable of holding, and before they had divested themselves sufficiently of the sensible heat they contained.

To retard fusion of a given quantity of iron and slag, less ore and flux were given to be melted; and thus, in a furnace of insufficient dimensions, the two functions were brought into harmony, of course at an expenditure of fuel.

It by no means, however, follows, that the quantity of fuel required to bring these two operations, fusion and reduction, into unison is the same in every case. In ores of similar richness this would be so, did the oxide of iron they contain yield its oxygen with equal facility. This, the Author has convinced himself, is far from being the case; and hence it need only be supposed, that the Scotch black-band was one half longer time, or thereabouts, than another ore, in surrendering its oxygen, to be satisfied that it was necessary to retain it one half longer time in contact with the reducing gases. It has been demonstrated at the Clarence Iron-Works, by many weeks' experience, that reducing the speed at which a furnace is driven is productive of no benefit, from the escaping gases rising in temperature; hence in two furnaces of the same size, that which is smelting an ore least susceptible to the reducing agency of carbonic oxide will consume an extra amount of fuel, commensurate with the relative facility with which the two kinds of ore lose their oxygen.

Time, then, is the element which is required to make amends for the want of readiness with which a particular ore parts with its oxygen. But this is not the only means available, for the

same result can be secured by a very moderate alteration of temperature. Thus, calcined Cleveland stone at 410° C. (770° Fahr.) lost 37 per cent. of its oxygen; but when the heat was raised to that of dull redness, it was deprived of nearly double this quantity, the time of exposure being the same in each case. Hence it need only be supposed that the temperature of the reducing gases, when using hot air, is a little more elevated, or that they are in a condition to communicate their heat more readily to the materials they surround, to account for the action of the hot blast.

The following is the language used by the Author elsewhere in reference to this mode of explanation :—[1]

"Independently of any increase of temperature in the upper portion of the furnace, the use of the hot blast introduces a change in the relation between the solid and gaseous contents, which will have the effect of accelerating the tendency towards an equalization of temperature of the two. By this action the ore is more speedily heated, and the gases, in consequence, are more quickly saturated with oxygen gas. This arises from the longer retention in the furnace of the carbonic oxide evolved by the combustion of a given weight of coke (when burnt with hot than with cold air); and this happens in the following way :—

"Let us imagine that a furnace of 6,000 cubic feet has conveyed into it, by means of the hot blast, 14,400 cwt. heat units per ton of iron, over and above the number it would receive were the air driven into it at the temperature of the atmosphere. This is equal to the heat from 6 cwt. of carbon burnt to carbonic oxide, which carbon can, therefore, be at once withdrawn from the fuel introduced with the charges.

"This quantity of carbon represents 38·8 cwt. of gases, which is equivalent to about 10 per cent. in the volume of those flowing up through the contents of a furnace using originally 60 cwt. of coke per ton of iron. During the time, therefore, each cwt. of carbon is engaged in fusing the iron and slag in the hearth, while in the act of being converted into carbonic oxide, the carbonic oxide thus formed is retained, by the diminution in its volume, one-tenth longer period in the furnace, and by so much its contact with the materials the gases have to heat and to reduce is prolonged. This effects a further saving of fuel, and, in consequence, a further reduction in the volume of gas is accompanied again by an addition to the time of retention of this gas in the furnace. This is continued until

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[1] *Vide* "The Journal of the Iron and Steel Institute," Vol. i., 1872, p. 49. "Chemical Phenomena of Iron-Smelting."

the fuel is diminished in quantity, as far as a furnace of the proper dimensions is capable of producing a ton of iron, which is not reached until the gases in bulk are a mere trifle above one-half of what they were when the blast consisted of cold air, instead of with the supposed addition of the 14,400 heat units in question.

"It is clear, under such circumstances, the reducing gases will be twice as long in contact with the ore they have to reduce, and with the material they have to heat, than when cold blast is employed."

That it is time alone which effects the change, and no mysterious virtue in the heat of blast, is proved by the experience at the Lilleshall works, where, by heating the air of a 53-feet furnace, precisely the same result in point of economising fuel followed, as was obtained by raising a furnace of this size to a height of 71 feet.

Neilson's invention, therefore, owes little of its value to the cause on which he supposed its usefulness was dependent; but it served to remedy a defect in furnaces of his time, viz., want of capacity, which defect, when removed, was as efficacious in saving fuel as the hot blast itself, *i. e.*, a ton of iron with cold blast could be made in a furnace 71 feet high with as small a consumption of fuel as was required when hot blast was applied to a furnace 53 feet in height, in each case identically the same materials being used.

Two great improvements in the smelting of iron have now been considered, viz., the use of heated air, and the increase of size in the furnace. In point of reputation the hot blast occupies by far the more important position; but it will be seen, from what has preceded, that in point of real merit, so far as economising fuel is concerned, Neilson's discovery is not entitled to this distinction, which is one it has acquired from priority of introduction, and from a supposed virtue believed to be the peculiar property of heated air.

These observations are at present limited in their application to the stage to which this inquiry has been brought, which consists in having proved that, in the matter of fuel consumption, a 71-feet cold-blast furnace performs as perfectly as one driven with heated air having an altitude of 53 feet. The 53-feet hot-blast furnace, it is true, turns out a larger make of iron than that blown with cold air (probably 200 tons per week against 120 tons), but on the other hand the latter, without any apparatus to maintain, or fuel to expend, for heating the air, is able to do its

work as efficiently, in point of fuel consumed in the furnace, as the other assisted by the more complicated appendage suggested by Neilson.

It now remains to consider, the prospect there is of constructing a furnace so large as to dispense altogether with the use of hot air, without a sacrifice of fuel used in the furnace itself; afterwards to examine the effect of uniting the benefit derived from a high temperature of blast with that obtained by enlarged capacity; and then to test the belief expressed by Mr. Siemens last May, that "the blast could not be made too hot for economical purposes, and that real progress in iron smelting must henceforth be looked for chiefly in that direction."[1]

The first portion of this inquiry has been already answered in showing that 25½ cwt. of coke are capable of evolving 93,000 cwt. heat units, the estimated number of units required for producing a ton of pig iron from an ore yielding 40 per cent. of metal. Discarding hypothesis, foundry iron was actually obtained at Lilleshall with cold blast for 27½ cwt. of coke, and forge iron in 1834, according to Dufrénoy, was smelted in France with 25 cwt. before the use of hot air was suggested by Neilson.

This reduction of 12½ cwt. of coke at Lilleshall was effected upon an ore only requiring, in a 53-feet furnace, 40 cwt. of this combustible. Whether it would be possible to force the air conveniently through a column of material so high as to be able to produce a ton of pig-iron from black-band with 25 to 27½ cwt. of coke with cold blast is a question which would demand consideration. This doubt arises from the circumstance that this variety of iron stone, parting with its oxygen so slowly, consumed in a low furnace 60 cwt. of coke per ton of metal, and would, therefore, obviously demand a much larger addition to its capacity, to bring its coefficients of fusion and reduction into harmony with each other, than an ore only taking 40 cwt. to smelt it under the same conditions as to temperature of blast.

There remains to be considered—a furnace sufficiently large to enable the ascending gases to divest themselves of their sensible heat, and to become saturated with oxygen, both operations it will be assumed being effected to the extent permitted by the nature of the process. Suppose now into such a furnace, instead of cold air, the blast was admitted at a temperature of 485° C. (905° Fahr.), the same effect in point of increase of intensity would follow as happened when the blast was changed from cold to hot in the

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xxxii., p. 364.

lesser furnace, and some of the extraordinary consequences, supposed to be due to this additional intensity of heat in the hearth should manifest themselves, if the value of the hot blast were dependent thereon. Such, however, is not the fact, for the furnace, having now sufficient capacity to permit the two functions of fusion and reduction to proceed in point of time in unison with each other, instead of one heat unit in the blast doing the work of three or four previously evolved by the fuel, each unit of heat thrown in with the air does no more duty than one unit produced by the combustion of coke in the inside of the furnace.

There is no doubt, with combustible matter of the same commercial value, it would be much simpler to obtain the necessary heat by the direct action of the blast on the fuel in the hearth of the furnace. Inasmuch, however, as the air is now heated by the escaping gases or by coal of little worth, there is, in spite of the law just enunciated, a notable advantage in the source of heat rendered available by Neilson's invention. The question, therefore, which presents itself is the extent to which it can be substituted for that generated by the more expensive description of fuel used in the furnace itself.[1]

The chemical laws, already alluded to, which regulate the power of carbonic oxide to deoxidize an ore of iron in presence of a gas having a contrary tendency, such as carbonic acid, impose a limit to the substitution of mere heat for heat accompanied by the carbonic oxide, the generation of which served as its source. The quantity of carbonic acid due to the reduction and carbon-impregnation of an ore of iron is that represented by 6·58 cwt. of carbon for each ton of metal. In the diagrams (page 118), it was assumed that, if the volume of carbonic acid materially exceeded 45 vols. to 100 vols. of the lower oxide of carbon, reduction was nearly suspended. In practice, however, it may be regarded as difficult, if not impossible, to saturate the gases with oxygen to an extent even to obtain this relation between the two oxides of carbon, owing to the slowness of the operation. As a rule, when the gases contain for 100 vols. of carbonic oxide, 40 vols. of carbonic acid, it may be assumed that the process approaches the extreme limit to which, in treating the ironstone of Cleveland, it can be carried. When the gases have absorbed a quantity of

[1] Conveying heat into the furnace by means of the blast possesses great advantages, enabling the smelter to pour in a supply where it is most required, without waiting for any change in the burden of coke and ironstone which come down into the hearth.

oxygen sufficient to establish the relations just mentioned, the weight of carbon consumed will be that represented by 21 to 21½ cwt. of good Durham coke. When this quantity of such coke is burnt to the condition of oxides in the proportions mentioned, the heat evolved is not sufficient to discharge the demand made upon it in smelting a ton of iron from Cleveland stone, and the deficiency is exactly that represented, by the quantity of heat usually contained in the blast at any well-appointed furnace on the banks of the Tees. In other words, if 25½ cwt. of coke, burnt under favourable conditions, can smelt a ton of iron with cold air, 4 cwt. of such coke can be saved, if into the furnace a quantity of heat can be introduced with the blast representing the 4 cwt. in question.

Supposing, however, that, instead of being content with the blast being heated just enough to afford an economy of 4 cwt., which would be about 485° C. (905° Fahr.), Mr. Siemens' recommendation is adopted, of raising its temperature say to 800° C. (1,472° Fahr.). This addition to the heat resources of the furnace will immediately be felt all over its contents, and as soon as it reaches the zone of reduction, where the temperature is such that the carbonic acid therein generated is inert on carbon, this condition of things experiences a complete change, and the superheated carbonic acid now dissolves coke, which is productive of loss, both from the cooling effect of the reaction and from the actual diminution of fuel arriving for combustion at the tuyeres.

The Author has proved this by repeated analyses, and he has invariably found, that just as any excessive quantity of heat was injected into the furnace with the air it received, so did there disappear a quantity of carbonic acid from the gases, corresponding exactly with the needlessly high temperature conferred upon the blast.

The advocates of superheated air have never fairly grappled with the figures obtained by the Author in his numerous experiments, and which in reality form the keystone of the whole question.[1] To go into these would require more time than the limits of such a Paper as the present would permit. Instead of doing this he will content himself with stating, that he has failed to deduce from the facts quoted by a recent writer, Mr. Thomas Whitwell, in his recommendation of superheated blast, any other view than one refuting the opinion laid down by Mr. Siemens.

Laying mere theory aside, actual experience demonstrates

[1] *Vide* "The Journal of the Iron and Steel Institute, 1871."

beyond all doubt, that this excessive heat is simply wasted in the blast furnace to which it is applied. At the Barrow works, the rich hæmatite of Lancashire is being smelted in a 61-feet furnace, with air heated to 1,100° Fahr. The consumption of coke is no less than it ought to be were the blast 200° below this temperature in a furnace of proper size; but in order to ascertain the effect of a still higher heat, the air was recently raised to 1,500° Fahr., or 400° Fahr. above its former standard. The iron neither became richer nor was there the slightest reduction in the consumption of fuel. In the vicinity of Middlesbrough are two works, both using the same ironstone—the one blown with superheated air obtained from fire-brick stoves, the other using air heated in the ordinary metal pipes, and consequently having a temperature about 400° Fahr. lower than at the neighbouring establishment. The consumption of coke at both over a whole year was, it is said, almost exactly the same.

The fire-brick stove possesses many advantages over that of iron, but among these, when applied to a sufficiently large furnace, the power of heating air beyond 900° Fahr. ought not to be counted, for the simple reason that the increase of temperature represents so much waste. If, on the other hand, mechanical difficulties prevent a particular kind of ore being treated in a sufficiently capacious furnace, the structural defect finds, no doubt, a valuable remedy in superheated air.

The solvent power, as it were, of the gases over oxygen having reached its limit when 30 per cent. of the reducing carbonic oxide has passed into the higher state of oxidation, is a barrier to further economy, because reduction then practically ceases. If, however, reference is made to the table of heat appropriation formerly quoted, it will be perceived there is a loss of nearly one-tenth of that evolved by the sensible heat carried off in the escaping gases. Appreciable as this is, it is less by one-half from a furnace of 12,000 cubic feet than it was from one of 6,000 cubic feet.

In the year 1869 the Author published a diagram (Plate 17) containing the results of repeated observation on this question, by means of which it was demonstrated, that a furnace 80 feet high, and containing 12,000 cubic feet, emitted the gases as cool as one twice this size. In this diagram the temperatures of the escaping gases as they leave furnaces of four very different dimensions are shown by means of a curve. Since that time larger and larger dimensions have been adopted in the North of England until a capacity of 41,000 cubic feet has been reached without, in the Author's opinion, a commensurate advantage

having been obtained. The maximum cooling and oxygen saturation of the gases are secured in a furnace of 16,000 cubic feet, and certainly the increase of make has not kept pace with the increase of size, as may be seen from the following statement:—

Furnace of cubic feet . . .		6,000	12,000	16,000	26,000	41,000[1]
Weekly make . . .	Tons	220	260	350	400	550
Weekly make per 1,000 cubic feet	„	37	23	22	16	13

In the discussion on Mr. Samuelson's Paper, previously referred to, Mr. Bramwell agreed with the Author, that there was a limit below which it was useless to hope to reduce the temperature of the escaping gases, but his conclusion rested on entirely different grounds from those assigned by the Author. The language made use of by Mr. Bramwell was as follows: "the incoming materials in a given time remained a constant quantity in relation to that of the outgoing gases, so that when a height was attained sufficient to give time for the incoming material to take up from the outgoing gases the whole of the heat which that incoming material was competent to absorb, any increase in time must be entirely useless."[2]

In this view no recognition is made of any influence which the chemical action of the reducing zone may exercise on the temperature of the gases. Indeed Mr. Bramwell infers, from his own observations on the Chenot process, that the deoxidation of iron ore is a heat-absorbing process instead of being one of heat evolution, as maintained by the Author.

The Author is compelled to dissent from both these expressions of opinion. If it were possible to intercept the 8,800 heat units escaping in the gases, or a portion thereof, the outgoing gases would no longer be "a constant quantity" to the incoming materials, for the simple reason that, apart from chemical considerations, the fuel might be diminished to the extent to which the loss of heat in the gases is reduced in quantity, and this diminution of fuel would alter the bulk of volatile matter leaving the furnace. Again, a slow rate of driving, in a furnace of a given size, by affording the gases a longer period of contact with the solids, ought to permit a more perfect equalization of temperature than a more rapid one, which is contrary to the actual facts of the case.

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[1] The effect of a large furnace of 41,000 cubic feet, producing less in proportion than one of 16,000 cubic feet, is that the charge for interest on outlay is about as 100 to 66 in favour of the latter.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxii., p. 360.

The Chenot process affords no light whatever in solving the question in point, because it differs essentially from the work of the blast furnace. It consisted in mixing charcoal and oxide of iron, and to effect reduction external heat was necessarily applied to the retort containing these two substances to compensate, Mr. Bramwell argues, for that absorbed in the operation.

If gaseous carbonic oxide is passed over peroxide of iron, carbonic acid escapes at a temperature more or less elevated, and from the apparatus itself there is also a loss of heat from radiation, convection, &c. Now, unless the heat generated by the reduction of this compound of iron by carbonic oxide is greater than the loss from the above-mentioned causes, external heat must be applied to continue the operation; but it might be a fallacy to infer therefrom that reduction was one of a cooling character.

In the case of the Chenot process with the reducing agent, charcoal, in the solid form, this application of external heat is still more necessary than where it is applied as a gas, because a portion of the resulting gas is carbonic oxide instead of carbonic acid, and the difference between burning carbon to the former instead of the latter compound is as 8,000 to 2,400.

But the question of obtaining a minimum temperature in the escaping gases, representing as it does in the largest furnaces 2 to 3 cwt. of coke, was deemed of sufficient importance by the Author to make it one of direct experiment on a large scale. This was performed by removing the calcined ironstone from the burden of a blast furnace, and replacing it with an equal weight of slag and flints upon which carbonic oxide was inert. The trial was continued for several hours, and the result was that, as soon as the ironstone was taken off, the temperature fell, and only began to rise again when it was replaced, proving that the reduction of oxide of iron is accompanied by an evolution of heat.

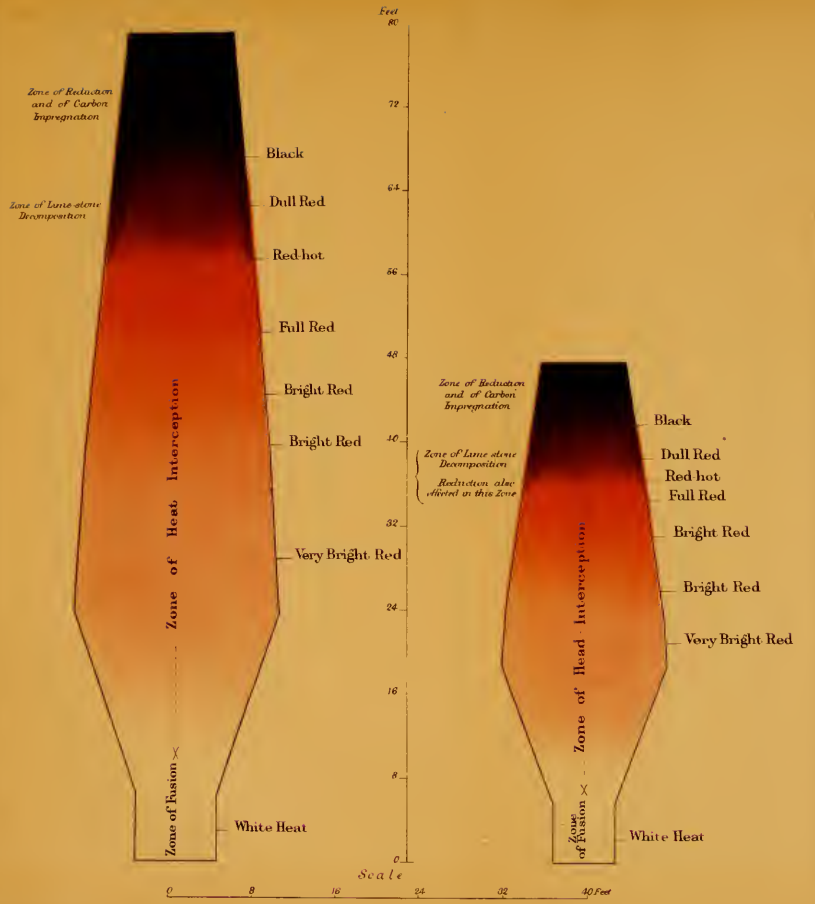
There are many circumstances which may interfere with a furnace of even the best construction performing its duty in an efficient manner; but it is obvious that if a blast furnace, from its deficient capacity, is working far below the limits within command, modifications of form may, as Professor Forbes suggested upon a former occasion,[1] be attended with important results. But if, as the Author believes, a furnace of 16,000 cubic feet with its blast at 900° Fahr. (482° C.) does its work as well, in point of consumption of fuel, as one double this size with a blast of 1400° Fahr. (760° C.), the inference is, in the smaller furnace the

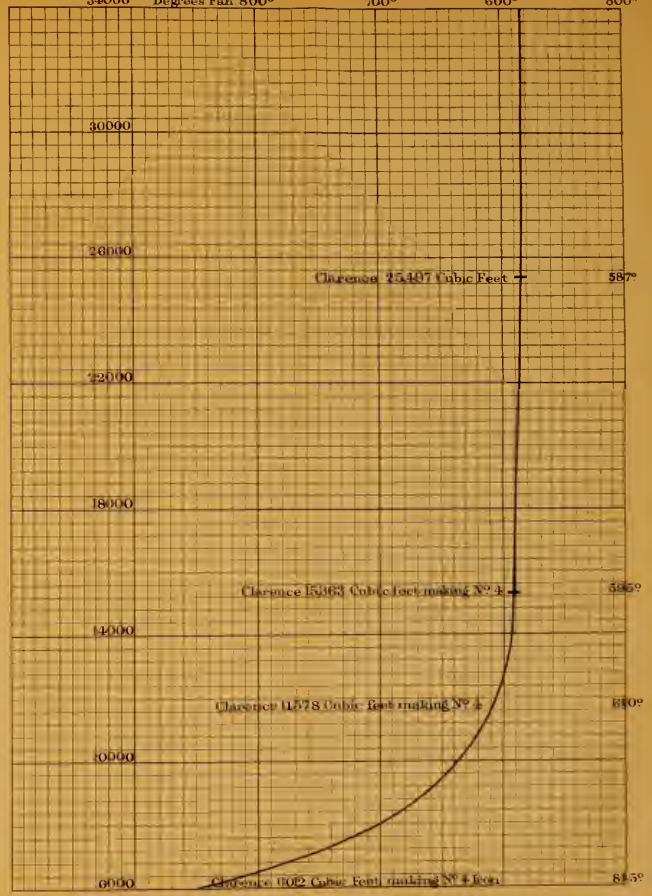
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxii., p. 361.

limit of economy has been reached in this respect, imposed by the nature of the operation as it is now carried on. Were it otherwise, any defect attaching to the lesser furnace blown with air at a lower temperature must have found a remedy in the larger receiving superheated blast. Under these circumstances, the Author conceives Professor Forbes is in error, when he supposes that mere shape in the furnace can further cool gases which have parted with all the heat they are capable of surrendering, or that the power of these gases to absorb oxygen can be increased beyond saturation. These are really the conditions which determine the whole question of the quantity of fuel required to produce a ton of pig-iron. Their study, however, is attended with considerable labour; hence the Author would warn an intending inquirer from hastily drawing any inference on the probable behaviour of one ore by his own observations on another. Indeed the phenomena connected with the operations of the blast furnace are liable to be affected by so many disturbing causes, that much caution is required to avoid arriving prematurely at any fixed opinions on the nature of a process so complicated as that of iron smelting.

The communication is accompanied by several diagrams, from which Plate 17 has been compiled.

[Mr. SIEMENS


Feet
80
72
64
56
48
40
32
24
16
8
0
Zone of Reduction and of Carbon Impregnation
Zone of Lime-stone Decomposition
Zone of Head Interception
Zone of Fusion
Black
Dull Red
Red-hot
Full Red
Bright Red
Bright Red
Very Bright Red
White Heat
Zone of Reduction and of Carbon Impregnation
Zone of Lime-stone Decomposition
Reduction also effected in this Zone
Zone of Head Interception
Zone of Fusion
Black
Dull Red
Red-hot
Full Red
Bright Red
Bright Red
Very Bright Red
White Heat
Scale
0
8
16
24
32
40 Feet


Capacity Cubic Feet
34000
Degrees Fah. 800°
700°
600°
500°
30000
26000
Clarence 25407 Cubic Feet
587°
22000
18000
Clarence 15363 Cubic feet making N° 1
585°
14000
Clarence 11578 Cubic feet making N° 2
580°
10000
8000
Clarence 8062 Cubic Feet making N° 3 Iron
845°

Mr. Siemens said that Mr. Bell had watched blast furnaces more carefully than almost any other metallurgist. Some of the facts brought out in this Paper were extremely interesting; amongst others the proof that the reduction of iron ore was a source of heat instead of, as was more generally supposed, the cause of loss of heat; and that reduction was effected at so low a temperature as 420° Fahr. Mr. Bell had endeavoured to show that in the blast furnace the different operations, constituting the process of smelting, might be carried on in such a way as virtually to complete one process before the other commenced; and from this the somewhat astounding conclusion was arrived at, that nearly all the advantages derived from the hot-air blast might be realised by simply increasing the size of the furnaces. The argument was not pushed to the practical conclusion, that the capacity of the furnace should be increased to the point of realising all the advantages of the hot blast, but the permissible temperature was limited to 960° Fahr., at which point it was considered that the maximum effect could be had with a furnace of limited capacity. This argument was based upon the supposition that iron ore was reduced at 420° Fahr.; and that the second action, which was that of carbonic acid splitting up in contact with carbon, could only be accomplished at a higher temperature. If, therefore, the carbonic acid had all been split up in contact with carbon, and a zone had now been reached at which no more unburning of carbonic acid took place, the whole remaining capacity of the furnace would be reserved for the final action—that of the reduction of the ore to the metallic condition, and the production of a large proportion of carbonic acid gas in the gases leaving the furnace. He thought, however, that iron ores, as a rule, were not reducible at the extremely low temperature of 420° Fahr., which was really below that of incandescence. In dealing with calcined Cleveland ore he had no wish to doubt the fact, but if it was considered what this ore consisted of, it would be seen why its reduction and carbonization took place at that low temperature. In calcining Cleveland ore 25 per cent. of volatilised matter was evolved; therefore the calcined ore must be regarded as a sponge, consisting of extremely divided particles of iron ore. This sponge being brought into contact with the reducing gas, the carbonic oxide was mechanically absorbed in large quantities, and the reduction of the ore facilitated. The sponge into which Cleveland ore was converted by calcination might in effect be compared to platinum sponge, which, when a current of hydrogen gas was directed upon it, absorbed that gas so violently as to produce ignition. Again, when a solid

bar of iron was exposed to a dry atmosphere, no appreciable oxidation would take place in one hundred or even in one thousand years. There were iron bars which, in old Roman buildings, had been exposed to the atmosphere for two thousand years and were not oxidized; but the same iron in a pulverulent condition would take fire instantly in a room, showing that the same material would behave differently under similar circumstances, according to its aggregate conditions.

He had paid considerable attention to the reduction of iron ores, and he had found that, whereas hydrated ores or spathose ores were reducible at a low temperature, the peroxides required a higher temperature; whilst there were certain ores which were not reducible at a temperature below 1,500° or 2,000° Fahr. Those were the dense magnetic oxides which had no gases to give out, but were perfectly dense, like a piece of glass. Such compact ores, he believed, were not reduced in the upper part of the blast furnace in the way supposed—viz., by a current of carbonic acid, but only in a lower part of the furnace after they had become liquid. Certain ores, such as Ilmenite or Marbella ore, had been known to pass through the blast furnace and to come out unchanged with the slag, notwithstanding the heat through which they had passed. He thought if such pieces of ore could tell a tale, they would speak of actions and reactions going on in the blast furnace which did not altogether tally with the beautiful stratifications Mr. Bell had shown. The Author's conclusion, that the hot blast could not be beneficial beyond a certain point, was mainly based upon the argument, that with the temperature of the blast the heat towards the top of the furnace was also increased. But the temperature of the blast affected the temperature at the top of the furnace in the contrary way to what Mr. Bell had in his argument supposed. If the temperature of the blast were suddenly raised, then indeed a rise would be perceptible throughout the furnaces, and the gases would escape at a somewhat higher temperature. In that case the same amount of oxygen would be introduced, and the same amount of carbon accompanied the charge; therefore there must be the same proportion of carbonic oxide and of carbonic acid issuing at the top, with an increase of temperature resulting from the greater importation of free heat with the blast. But if at the same moment when the temperature of the blast was raised, the relative quantity of coke in the furnace could be diminished, to the point of producing not more than the requisite amount of heat, then a diminished quantity of products of combustion would have to impart its heat to the same quantity of ore; and inasmuch as the

relative quantity of matter to be heated and smelted would be increased, it followed that the temperature of the escaping gases must be less than before, and that there must be advantage in raising the temperature of the blast.

As to the effect of the increased temperature of the blast upon the temperature of the crucible of the blast furnace, he had explained his views very fully on a former occasion, when the Author of the present Paper argued on the other side of the question.[1] He might now state that, in advocating high temperature of blast, he did not look for any great increase of heat in the zone of fusion. He looked for the advantages of hot blast to the greater importation of heat into the whole economy of the blast furnace, resulting, he believed, necessarily, in great saving of fuel.

In the statements of results which were frequently put forward, certain elements were generally wanting; and the most important of these was the relative quantity of blast used. If the temperature of the blast was increased without its being stated whether the same quantity was injected relatively to the amount of carbon in the charge, no positive conclusion could be arrived at; but these discussions would assume a more definite character, if the amount of blast was in all cases stated, and if the working of the furnace was only taken after it had been readjusted after a change of temperature to a minimum percentage of carbon with the charge. It could be easily conceived that with too much carbon the blast would produce an excess of carbonic oxide, and this would issue at the top of the furnace at a very moderate temperature. It might be argued, in that case, that the hot blast produced unfavourable results; but if an increasing quantity of ore had been mixed with the coke, and the proportion gradually increased with increased temperature of blast till a positive minimum, to insure fusion of the mass, had been reached, the result would have been much more favourable. The general basis which he went upon was, that if free heat was imported into the furnace with the blast, that heat was produced economically in burning fuel into carbonic acid; whereas the blast furnace could at most produce carbonic oxide, with a proportion of, say, $\frac{1}{5}$th or $\frac{1}{4}$th of carbonic acid. The Author had clearly shown that, in producing carbonic oxide, only about $\frac{1}{4}$th the amount of heat was produced from a given quantity of coal as when carbonic acid was formed. Therefore every unit of heat

[1] *Vide* The Iron and Steel Institute—Transactions, vol. i., p. 222.

applied to the blast outside the furnace represented really 3 units of heat produced by the combustion of coke within.

Mr. B. Samuelson, M.P., said he regarded the Paper to a great extent as the sequel of the one he presented to the Institution last session.[1] It dealt with the chemical aspect of the question, which seemed to him to be rather out of place in the Institution. It was as if, instead of discussing a water-works plant—which was properly within its scope—intricate theories were broached of the effluence of water from orifices; and so, instead of a practical discussion upon the various features of any scheme, theories were put forward which, probably, would be better elaborated out of doors, and the results afterwards brought to bear upon practice.

The main question to be considered in the erection of a blast-furnace plant was, that it should be economical from an engineering point of view. In regard to this, a very apposite statement had been made in the Paper,—which applied equally to every branch of pure engineering practice,—viz., first ascertain the conditions, and then endeavour to adapt the plant to those conditions. He wished the Author had carried this theory into practice more completely, and had stated what ought to be the relative dimensions and shapes of the different zones of the furnace. But nevertheless the assumption had been made, that in all the large blast-furnace plants erected of late there was waste of capital, and corresponding waste of interest, in the proportion of 100 to 66. It was not stated how this result was obtained; but having endeavoured to check the calculation with certain presumed data, he found, by taking the quantity of pig iron made, and assuming the cost of blast-furnace plant to be in the ratio of the cubical contents of the furnace in which the iron was produced, the result would come out somewhat as Mr. Bell had stated. But here there were two fallacies. In the first place, it was assumed that a blast-furnace plant with a capacity of 15,000 or 16,000 cubic feet would produce 350 tons of pig iron; while blast furnaces of 26,000 and 41,000 cubic feet capacity would only produce 450 and 550 tons. But he begged to point out that blast furnaces of 26,000 and 41,000 cubic feet capacity respectively would produce 450 and 550 tons of iron of a better quality than No. 3; and the statement left it to be understood that the 350 tons produced by the smaller furnace would be of equally high quality. That was contrary to the experience generally of the Cleveland district, and it was that district upon which the reasoning was founded. He believed it was contrary

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxii., p. 329.

to the experience of iron manufacturers in that district that a blast furnace of 15,000 or 16,000 cubic feet capacity should be able to turn out 350 tons of foundry iron—that was to say, iron of equal quality to that of which 450 to 550 tons could be produced in the larger furnaces. He believed that in quality, or what was technically known as 'numbers' alone, there would be a difference of at least one number, which meant, multiplied by the number of tons, not merely the interest upon the difference in the cost of the larger, as compared with the smaller plant, but the interest upon the entire plant. The improvement in 'numbers,' irrespective of any other economy, would be equal to the interest upon the entire plant put down to obtain the larger make. The second fallacy was, that the cost of blast-furnace plant had comparatively little relation to the cubical contents of the blast furnace which formed a part of it. As he had pointed out, on the occasion of the reading of his Paper, the blast furnace itself only cost from one-fourth to one-fifth of the cost of the entire plant; and in nearly every other item except the blast furnace itself, the cost was independent of the cubical capacity of the blast furnace. The dimensions of the blowing engines and boilers, of the heating stoves, and of the calcining kiln, were as nearly as possible not in the ratio of the cubical contents of the blast furnace, but in the ratio of the amount of air blown in, of coke consumed, and of iron produced, or, at any rate, in a ratio compounded of those items, between which there was comparatively little relative difference. And even in the cost of blast furnaces themselves of various dimensions, the cost did not increase in the ratio of the cubical contents or of the square of the diameter multiplied by the height, but in a much smaller ratio. The Author would find in going through the calculation that, instead of the ratio of cost of blast furnaces large and small being as 100 to 66, it would be nearly as 100 to 92, and Mr. Samuelson thought this slight additional capital would be more than covered by the saving of wages, and in other ways, quite apart from any saving of coke. But he would venture one step further, and, without entering into the intricate chemical questions which had been brought before the Meeting, would assert that there was a saving in the amount of fuel consumed in the larger blast furnaces, and that therefore there were fallacies in the theory and in the facts brought forward on that subject. From the figures in the Paper it was implied, although perhaps not absolutely stated, that it was impossible, under the condition of the Cleveland iron manufacture and dealing with the average quality of Cleveland ore, to produce a ton of iron

with less than 23½ cwt. of carbon. Thus, it was stated that 55,000 heat units were consumed in reducing ores, which, from their description, corresponded with the Cleveland ores; and further, that these 55,000 heat units divided by 2·400 gave 22·9 cwt. of carbon, and this, with certain allowances, gave 23½ cwt. of carbon, or 25 cwt. of Durham coke.

Mr. Bell said that calculation was based on smelting the Cleveland ironstone with cold blast instead of hot blast.

Mr. Samuelson explained that, although it did not appear on the face of the calculations referred to that the consumption of fuel applied to iron made with cold blast, yet he was convinced, on further consideration of the entire Paper, that the Author intended to convey this, and that more careful attention on his part ought to have made it apparent to him. At the same time he thought that some of the values were not correct, and that more especially those of fusion of the metallic iron and slag and loss by waste heat in the escaping gases were excessive.

Mr. J. T. Smith remarked that there was one subject on which practical men would like some explanation, and that was as to the effects of different temperatures of hot blast in the furnace. The result of the experience of the West coast manufacturers, and of experiments recently carried out for several weeks together, was that there was no economy of fuel in heating the blast beyond 1,100° Fahr.: but at the same time it was found that benefit was derived from increasing the temperature from 700° to 1,100°. At the latter temperature he was convinced there was a material saving in the quantity of coke used in the furnace over working with 700°, but that beyond 1,100° there was no saving. There were few establishments where there was an opportunity of trying the effect of a temperature beyond 1,100°; but at the Barrow Works this was possible. The experiments were made with hematite ore; the contents of the furnace being 13,000 to 14,000 cubic feet, and the quantity of blast passed into the furnace per minute from 11,000 to 12,000 cubic feet. He could not state off-hand the quantity of blast necessary to produce one ton of metal, nor how many minutes it took to reduce a ton of ore: but he repeated, with the same quantity of blast, with similar materials, and with the same furnaces, no benefit as to economy of fuel was derived from a temperature of blast beyond 1,100°. These remarks were made in reference to the statement of Mr. Siemens, that any quantity of heat passed into the furnace through the blast must be productive of advantage.

Mr. Siemens suggested that Mr. Smith should supply some

explanation as to the conditions under which the experiments were made. He would like to know how the quantity of blast used was ascertained,—inasmuch as if it heated to 1,100° it would occupy a different volume to what it would if heated up to 1,400°, also whether the size of the tuyeres was increased in proportion to the degree to which the blast was heated, so as to admit in both cases the same weight of air per minute. To arrive at complete data the quantity of blast used should be known, as well as whether the quantity of coke was reduced to a minimum under the varied condition of things before the results were noted.

Mr. J. T. Smith said he was not at present prepared to supply that information, because the apparatus broke down under the very high temperature to which it was subjected. The position of the experiment was this:—a furnace supplied with Cowper's stoves, equal to raising the blast to a very high temperature, was worked for fourteen days at temperatures of from 1,050° to 1,100° Fahr. the blast being tried every half-hour. The coke, ore, and limestone were carefully weighed. The intention then was to have gone on for a fortnight with a blast at a temperature of 1,500°, and after that for another fortnight with the apertures through which the blast entered into the furnace increased in size, to compensate for the increased volume resulting from the difference of temperature. At the end of eight days it was found that, with a temperature of blast of 1,500°, the valves failed; and after that time irregularities in the working of the valves caused stoppages in the furnace, and prevented really reliable experiments being made. The result, however, of the eight days' working was exactly the same per day as the working of the previous fourteen days with the blast at a temperature of 1,100°. The opinion he had arrived at was, that the furnace would have made a larger quantity of iron if the size of the tuyeres had been increased to have passed the same weight of blast as in the experiment at the temperature of 1,100°; but the quantity of coke per ton would not have been reduced. Iron manufacturers cared little about 50 tons per week more or less as the production of a blast furnace; their chief and proper aim was the reduction of the quantity of fuel required to make a ton of iron.

Mr. G. J. Snelus said he had gone over the calculations in the Paper, and in many respects agreed with them; but there were certain conditions of these experiments about which there was no information. He did not think it was sufficiently considered that a great deal depended upon the shape of the furnace. He had found by tracing the phosphorus, when making Bessemer pig iron,

that if he changed the burden of the furnace from ordinary iron to Bessemer pig it took fully a fortnight to clear out the old charge; while if he changed the burden from Bessemer pig iron to ordinary pig iron he noticed the change in twenty-four hours. This proved that a good deal of material charged into the furnace found its way rapidly through the centre or some other part of the furnace, while another portion remained there a much longer time than was generally supposed. If the material found its way rapidly down the centre of the furnace, a great portion of the force or proper duty of the fuel must be destroyed; and if phosphorus found its way down rapidly it was almost certain that a good deal of iron ore found its way too, and this would react upon the carbon and silicon in the pig, and would change the "make" of the furnace from "grey" to "forge," or "white" pig. The furnace manager, then, to bring the iron back again to grey put on an increased quantity of fuel, which was of course so much wasted, in the sense that it was only used to overcome a defect not of height or capacity altogether, but probably of form of furnace, size of top, method of charging, or even size of pieces of ore. No doubt the amount of fuel used was frequently excessive, simply from an irregular method of charging the furnace; and as there were no data as to the way in which the furnace alluded to had been charged, it was difficult to judge of its efficiency in point of economy of fuel. He agreed that reduction of iron ores was more a matter of time than of temperature. He had made experiments upon most of the classes of ores used in England, and he had found the ordinary Bilbao ore was reduced, in point of time, more rapidly than the denser ores of the Cumberland district, or even than the magnetic ores. The Bilbao ores could be perfectly reduced at a low temperature, and he had reduced the Marbella ore in a solid state in a cast-iron tube, and therefore at a temperature far below 2,000°, so perfectly that he could cut the metal with a knife. Excessively high temperature probably facilitated reduction, but was not an absolute necessity for the reduction of any ore. On other points there was not sufficient information with respect to the experiments from which to draw conclusions, or to go into the question so accurately as the figures in the tables indicated might be done.

Mr. E. A. Cowper remarked that the Author asserted that the same advantage could be got by increasing the size of a small furnace, as by increasing the temperature of the blast. No doubt practically the saving obtained by increasing the size of a small furnace could be effected by simply increasing the temperature of

blast. To the majority of ironmasters this should be a very satisfactory fact, as by far the largest number of blast furnaces were of moderate dimensions, and some of them necessarily so, on account of the tender nature of some of the materials used, particularly the coke, which often would not bear a great superincumbent weight without breaking down to powder. Besides, some ores lay so close and compact, either when first put into the furnace, or after they had been subjected to the action of the furnace for a time, that it was impossible to get the blast freely through, if a furnace of great height was attempted. But if the majority of blast furnace owners could make moderate-sized furnaces work as well as the very large new ones, it would be a great advantage to them, and it was a fact that the higher temperature of the blast produced this effect.

So far there was very little difference between Mr. Bell's opinion and his own. He would not attempt to follow the chemical reasoning as to what ought, or ought not, to take place in a blast furnace under particular conditions, for the circumstances which governed or influenced the good working, yield, quality, and 'make' of a furnace, and the economy of all the materials used, were too numerous to discuss. He would give a statement of actual facts of the working of the same blast furnace with different temperatures of blast, there being no alteration whatever in the blast furnace itself, further than the adjustment of the size of the tuyeres, which was absolutely necessary to obtain the best results. It was obvious that as a temperature of 480° increased air of ordinary temperature to double its volume, so as the temperature of the blast was increased must the size of the tuyeres be increased, if it was intended that the proper quantity of blast should enter the furnace. The results obtained with this furnace, working for several years, with the ironstone, coke, and limestone of the same quality, the same amount of blast, and under the same management, showed that about 24 cwt. of coke was the consumption when blast at a temperature of 1,000° Fahr. was used. He believed there were a few furnaces that consumed 23½ cwt. of fuel per ton of iron produced, but there were very few works where the temperature of the blast was well kept up to 1,000° with cast-iron pipe stoves; indeed if the temperature was kept up to that point the stoves were constantly in danger, and might at any time be ruined in five minutes. When he first attempted to raise the temperature of the blast at some works in Cleveland, the temperature commonly used there and elsewhere did not exceed 750°; but as soon as he had got a furnace at work

at a temperature of 1,150°, and the advantages became known, there was a general raising of the temperature of the blast, and to his own knowledge a good many cast-iron stoves were sacrificed in the attempt. Then, by further improvements, in the course of years he ascertained by long-continued working at various temperature, that there was a saving of 4 cwt. of coke when working at about 1,420° Fahr. as compared with 1,000°. Inasmuch as the consumption of fuel was 20 cwt. of coke per ton of iron, the saving was most satisfactory, particularly when accompanied by a largely increased 'make' from the same plant of furnace, blast engine, boilers, &c. Again, in place of burning a less quantity of coke, it was quite possible to burn the same quantity of coke, and with it make a greatly increased quantity of iron, thus having about 20 per cent. more iron on which to take profit, whilst the coke per ton was greatly reduced.

The late Mr. Neilson, to whom was due a debt of gratitude for his admirable invention of the hot blast, was always in favour of raising the blast as high as practicable. Mr. Neilson said, in speaking of his stoves, "A very important step in advance had been made by giving the means of raising the temperature of blast much above the extreme limit practicable with the present ovens, and he considered this would be productive of the greatest benefit in the working of the blast furnace. . . . . He had always wanted to get a very high temperature of blast, and was convinced that, now the advantages of increasing the temperature of hot blast had been so clearly established by experience, advantage would be taken of every means to raise it still further."[1]

He thought Mr. Bell would agree, that the Cowper stoves were safer than iron pipes for any temperature, and that pipe stoves were unfit for a temperature of 1,100°, although it had occasionally been reached for a short time. Ironmasters had long been trying to raise the temperature of the blast, and many would soon have that advantage, as he had between seventy and eighty stoves under licence in England and abroad.

Professor D. Forbes remarked, that the object of the Paper was to maintain the opinion, that the working of blast furnaces had already arrived at perfection—at least as regarded the dimensions of the furnace and the heat of the blast applied in working them. He opposed that opinion on a former occasion, and he did so now. He admitted that the larger furnaces had not as yet produced effects equal in proportion to the increase in the size, but he main-

[1] Inst. Mech. Engineers—Proceedings, 25th April, 1860, pp. 65 and 66.

tained, as far as experience had gone, that there had been appreciable benefits from what had already been done in this direction; and that there had been greater economy in the use of the larger furnaces than in the use of the smaller ones which previously obtained. The question might be considered from two sides, viz., from the chemical or the physical side. Before an audience consisting for the most part of civil engineers, he would confine himself to those parts which, as a manager of blast furnaces, he had verified in practice. Mr. Bell had endeavoured to prove that perfection had been very nearly attained, for the reason that theoretical calculation of what a furnace could do agreed so closely with what was found in practice: therefore it would seem there was not much to expect in future from improvements in the furnaces. It had been very truly said that nothing was more deceptive than figures; and certainly it was so in this case: because, in an elaborate calculation like this, the greatest care should be taken, that the data on which the calculation itself was founded were established facts. What, then, were these data. In the first place, with regard to the temperature of fusion of iron, it was of course impossible to calculate what amount of caloric was required to do the work of a blast furnace unless it was first determined with precision what was the temperature at which iron melted. Now, the best authorities were greatly at variance on this point, evidently owing to the pyrometers at present in use being very imperfect instruments (unless Mr. Siemens' electric pyrometer turned out to be successful, which he had not had as yet the opportunity of fully trying); and it would be found that the melting point of iron was consequently given at various temperatures ranging between 1,050° to 1,812° C. With such differences, it was impossible to take either of those figures as the basis of the calculation, without obtaining results totally at variance with one another. Then, again, he did not agree that all slags melted at about the same temperature, as indeed some were extremely infusible, and others very fusible. Here came another point, and a very serious one, in the calculation, that it was not the point of fusion of the slag but the heat at which the slag actually formed in the furnace, which had to be considered. The temperature at which slag was formed, and the temperature at which the molten slag, once formed, could remain liquid, were totally different. Professor Plattner had made elaborate investigations into this subject, and had found, in the case of blast-furnace slags, that the temperature at which slag was formed was 1,846° C., while the temperature of the molten slag was only 1,431° C.; so that as one or other of these figures as taken was

the basis of calculation the results would be quite different. In some experiments he had put two crucibles into a furnace, one containing the mineral ingredients which in the blast furnace formed the slag, and the other a portion of slag itself, when he found the slag was melted long before the other. Consequently it followed that in a blast furnace there must be taken into consideration the greater heat required for forming the slag before it came to the molten state,—not the mere melting point of the slag itself.

As to the shape of the furnace, the Author seemed to think the great utility of the higher furnaces and larger capacity existed solely in the capability of the upper part of the furnace to absorb the extra heat formed below in the focus of fusion. In this opinion he disagreed. A modern iron blast furnace was a large instrument, and rather an expensive one to work with; but smaller yet analogous experiments could be made. He therefore took a couple of copper blast furnaces both of the same size—*i. e.*, of the same cubical capacity—each furnace being 15 feet high, but built in totally different forms. The conditions otherwise were the same in both. In the larger iron furnaces, which had been increased from 6,000 to 30,000 cubic feet in capacity, the belly of the furnace had been mainly enlarged, and the focus of fusion had not been increased in the same proportion. He had smelted as much as 10,000 tons, so that the experiments were not on a small scale, and the results he thought could be relied upon. In those experiments he diminished very largely the upper part of the shaft, and increased the focus; consequently, whilst the smelting power of the furnaces was greatly increased, the gases went out so cool at the top that they were hardly capable of burning paper, whereas but a few feet below the heat was very great. This was a proof that the alteration of form might be of the utmost importance. The mistake had been not in the larger capacity of the furnaces, but that they had been made very capacious above and not sufficiently capacious below, where the whole of the smelting work was going on. As a step in this direction, he might instance the case of the Raschette furnaces in Russia. He did not consider them perfection, but still those furnaces were doing more work than, according to their capacity, they could have been expected to do; and he had no doubt, by a modification of form in the larger furnaces, still higher results would be obtained. It was not a question of mere capacity, but of how the internal dimensions of the furnace were arranged.

He was still of opinion that the blast had not yet been employed too hot. But increased temperature of blast meant increased engine

power and larger tuyeres, or the quantity of oxygen sent into the furnace would be diminished, since the higher the temperature, the greater became the volume of the air. In practice, however, the quantity of oxygen in the air was often actually reduced, and more work was expected to be done merely by the increased temperature of the blast. This, he believed, was one reason why the results hitherto had not been more satisfactory and conclusive.

Mr. T. Whitwell said there was a remark in the Paper with regard to the "proper size" of furnace. The Author took it for granted that a "proper sized furnace" must be one of 12,000 to 15,000 cubic feet capacity, no matter what was the material to be smelted; whereas it appeared to him that every furnace must be built to suit the material to be operated upon. It was evident that in every furnace there must be proportions of height and diameter at which minerals were reduced in the most economical manner, a proper quantity of blast being injected into the furnace. If those proportions were exceeded, true economy could not be looked for. The furnace, therefore, that did its work best on any given material was the proper size of furnace for that material, whether of 15,000 cubic feet capacity or less. One furnace at Consett had been examined two years ago by Mr. Bell, who stated that it contained 9,114 cubic feet; and when 6,000 cubic feet of blast per minute were thrown into it at 1,350°, the product was 380 tons per week of grey iron, from material containing 46 per cent. of metallic iron, with a consumption of coke of 18 cwt. per ton of iron. But when into the same furnace 8,000 cubic feet of blast per minute, instead of 6,000, were forced at a temperature of 1,150°, the product was 480 tons per week in the place of 380, with a consumption of $19\frac{1}{4}$ cwt. of coke per ton instead of 18 cwt. The results, with a consumption of 18 cwt. of coke, extended over a year and a quarter; but since the furnace had been driven up in its make 25 per cent., the temperature of the blast being lowered, it had not worked so economically as during the previous period. He might say with regard to temperature of blast, so satisfied were the Consett Company of the benefit of having constantly a high temperature of blast, that they always kept as nearly as they could to 1,400°; and the furnaces were each producing an average of 457 to 460 tons of iron per week. The furnaces were 55 feet high; some with 20-feet, others with 21-feet, and one with 22-feet-6 inches diameter of bosh. The Author had contended that, in Cleveland, with furnaces of proper dimensions, viz., with a capacity of 15,000 or 16,000 cubic feet, it was unnecessary to raise the temperature above 900°, and that then the best results were

obtained, any higher temperature being accompanied by waste. But so far as his knowledge as a practical iron-smelter went—and he had visited the works of most of the iron-makers in Cleveland—the Cleveland ironmasters were working as nearly as possible at a temperature of 1,150°; and the highest temperature of blast, so far from being a source of waste, was known to be absolutely indispensable in producing regularity of quality, and correcting the many maladies to which the blast furnace was liable, resulting from bad coke, badly-calcined stone, wet, accidents, and other causes. The engineer of one of the companies most recently started had said, the furnaces were being worked with blast at a temperature of 1,190°, as indicated by Siemens' copper ball pyrometer, which he regarded as superior to all others, inasmuch as the longer it was used the lower temperature it showed. Other instruments got to show a higher temperature; but Siemens' pyrometer consisted of a copper ball of a certain size which, when heated, was plunged into an imperial pint of water; the ball became reduced in bulk by frequent use in very hot blast, so that the relative proportions of the water and the copper became changed, and the indications were always rather within the estimate than otherwise. Increase of height in a furnace without increase of temperature would not give true economy. In proof of this he might state that about a year and a half ago, some furnaces in Cleveland were rebuilt, and raised from 55 feet to 80 feet in height, having boshes of 26 feet, and a capacity of 26,000 cubic feet. Those furnaces were worked at 850°, or 50° below the point stated by Mr. Bell to be the most economical, and consumed 24 to 25 cwt. of coke per ton of iron, or 2½ cwt. more than the alleged proper quantity of coke per ton of pig. The Thornaby furnaces, 60 feet high and a 20-feet bosh, with blast at 1,100°, worked over the same period on similar material with 23 to 24 cwt. of coke per ton of iron, though the dimensions of the furnaces were 12,000 feet as compared with 26,000 feet in the other case. From what had been said by Mr. Smith, of Barrow, it might be supposed that there was a difficulty in working at high temperatures on account of the valves giving way; but, as far as Consett was concerned, four furnaces were in full blast with eighty of his water valves and seats. Of these, forty had been at work for nearly a year and a half, with blast from his firebrick stoves at a temperature of from 1,200° to 1,450°, without any failure of the apparatus.

Mr. I. Lowthian Bell, in reply upon the discussion, observed that Mr. Samuelson supposed the fact had been lost sight of, that the larger furnaces might make better iron than those of inferior

dimensions. That was a mistake. The object had been to compare consumption of fuel; but it would have been a fallacy to say, two furnaces using the same quantity of fuel per ton of iron were working with equal economy, if one was making No. 1 and the other white iron. Hence, when it was said that a furnace of 16,000 cubic feet capacity performed its duty as efficiently as one of 26,000 cubic feet, the quality of the product was not lost sight of; and in stating that such were the working results he spoke from some years' experience. Again, Mr. Samuelson pointed out that, in the actual increase of cost in a plant embracing furnaces of the largest size, it was the furnace alone which was more expensive, the blowing engines, heating stoves, &c., remaining the same as before, and that the interest on capital was not in the proportion of 100 to 66, as he maintained, but as 100 to 92. To this he would reply that his remarks about interest applied solely to the furnace itself.

He had ample experience of the importance of proper attention being given to both the shape of the furnace and the mode of charging; but his observations had reference to the most perfect action of the furnace, and perfect action implied perfect treatment.

It appeared to be thought by Mr. Siemens, that his argument was partly founded upon the action of the blast furnace being susceptible of division in accordance with the diagrams he had exhibited; and that it was necessary to suppose each operation in the smelting process was performed in one division or zone, and in no other. Now, this view was contrary to his expressed meaning. He maintained that it was a convenient mode of describing the operation; and he had not the slightest doubt the more those distinctive zones of action were kept separate the better and more economical were the results; but it was not less true that slight alterations in materials, in the atmosphere, and in charging, might and did considerably modify the work carried on in those different zones, which led to a deviation from what he on another occasion spoke of as the perfection of blast furnace working.

He had never stated that the hot blast was not a *bonâ fide* improvement. On the contrary, he stated and believed that in Neilson's time it was one of the most important improvements which ever had been introduced into the manufacture of iron. Nevertheless he found that, by raising the height of a furnace from 53 feet to 71 feet, the consumption of coke per ton of iron was reduced from 40 cwt. to about 28 cwt., which corresponded exactly with that obtained by heating the air to about 800° or 900° Fahr.

Again, in the opinion of Mr. Siemens, the value of his views were dependent on an ore of iron being reduced at 420° Fahr.; but he alleged that reduction commenced at a temperature of 420°, and was not complete until the ore reached a point in the furnace where the temperature was about 1,000° Fahr. In his experiments many kinds of ores were operated upon, and it was somewhat remarkable that of all ores tried, that of Cleveland was about the least susceptible to the reducing action of carbonic oxide. It was true the denser ores, such as the magnetic oxides, in their natural state, were slow in yielding oxygen to carbonic oxide. He had made a trial of Marbella iron ore. In its raw state it lost, at a temperature of melting zinc (782° Fahr.), in nine hours only about $\frac{1}{4}$th of the oxygen removed from calcined Cleveland ironstone; but when the Marbella ore was previously heated red-hot, its loss in this respect was equal to that of Cleveland, and its power of splitting up carbonic oxide was remarkably intensified. Thus, while in its raw state only about 3 parts of carbon per 100 of iron were thrown down against 6·7 parts in the Cleveland, when the ore of Marbella was roasted 167 per 100 of iron were found in the ore which had been operated on. The specimens were acted on simultaneously, by exposure to the current of carbonic oxide in a vessel kept hot by a bath of melted lead, and the temperature ascertained by slips of metal. In this case zinc melted and antimony was not changed; the heat therefore was between 782° and 842° Fahr.

He had been found fault with, as well as Mr. J. T. Smith, of Barrow, for not giving the quantity of blast received by the furnace in different experiments. The question of this quantity was spoken of as if it were easy to measure the air going into a furnace, while in reality it was very difficult. The fact was, that no engine drove out of the blowing cylinder all the air it compressed, and the loss in the hot air apparatus prevented the quantity being ascertained by displacement. It was equally difficult to calculate the volume by the area of the blast pipes, which were always being altered, by changes in the obstruction offered by the materials in the furnace itself. Let it not, however, be supposed, in the estimates he had given, that the quantity of air had been overlooked; indeed, without knowing how much air was consumed, no calculation could be made how much heat was conveyed by the blast into the furnace. In his opinion the only way to obtain this indispensable knowledge was by the aid of the chemist, and he must be careful in coming to a conclusion. The mode adopted was analyses based on the escaping gases, but as these varied much in composition, a sufficient number of experiments

must be made to get an average result. This being done, and the quantity of carbon used per ton of iron entering the furnace being known, and analysis affording the relation it bore to the nitrogen in the gases, the weight of air used was then found. To show how near to the truth these calculations were, he would quote one of the best among his numerous analyses :—

	Cwt.
Carbon per ton of iron in coke and limestone	17·35
Less taken up in iron . . .	·60
Weight of carbon in gases	16·75

Average composition of gases :

			Carbon.	Oxygen.
Nitrogen	54·10			
Carbonic acid . .	17·43	=	4·75	12·68
Carbonic oxide . .	28·00	=	12·00	16·00
Water (from coke) .	·45			
Hydrogen (from blast)	·07			
Cwt. . . .	100·05		16·75	28·68

Hence the blast per ton of iron was—

Nitrogen, as above	54·10
Oxygen therewith	16·16
Moisture	·81
Cwt. . . .	71·07

The proof of its correctness was ascertained as follows :—

Oxygen per ton of iron, as above	Cwt.	28·68
Brought in by blast, as above	16·16	
Moisture in blast would give	·72	
Iron ore from oxide of iron, phosphoric acid, &c. .	9·00	
Limestone	2·59	
		28·47
Difference for experimental error, &c.		·21

Air highly superheated was the direction in which economy was chiefly to be sought for, according to Mr. Siemens. He, on the contrary, considered that an equilibrium in the opposing actions at work in a blast furnace set a limit to this, because, after the gases exceeded a certain temperature, a secondary action was set up, by which carbonic acid was returned to the state of carbonic oxide, and this neutralized the effect of the extra heat added to the air. Mr. Siemens practically said it was not so, but he did not support this experimental proof. Mr. Siemens

seemed to infer that he had first propounded a theory and then sought for his facts. He admitted at an early period having stated his disbelief in the power to apply beneficially the blast heated to the extent anticipated by others, for two reasons, first, by decreasing the fuel the air decreased, so that when the diminished quantity of blast had to carry an increased quantity of heat its temperature rose more rapidly than some had supposed. Thus, if a ton of iron could be made with about 21 cwt. of coke at a temperature of 811° Fahr., the reduction of the coke to 15 cwt. required a rise of temperature, *cæteris paribus*, to 2,289° Fahr., which was probably unmanageable.

The change in the composition of the gases exerted, as he had said, a cooling effect, the extent of which at the period just referred to had not been determined. This cooling effect was manifested in the diminution of carbonic acid, as might be seen by the following table, in which was exhibited the composition, in round numbers, of 1,000 units of the heat evolved in blast furnaces, the gases of which were carefully analyzed:

Temperature of blast	900°	1100°	1320°	1360°
1. By production of carbonic oxide	480	500	490	510
2. By blast	130	150	160	190
3. By production of carbonic acid from carbonic oxide . . .	390	350	350	300
Units . .	1000	1000	1000	1000

It would be seen that as the relation of blast heat increased, that from the conversion of carbonic oxide to carbonic acid decreased.

Let the effect be now examined of reducing the weight of coke so as to avoid the high temperature of the gases with superheated air, and the unburning of carbonic acid. Two tables were here given; in the first a ton of iron was supposed to be produced with 21 cwt. of coke, with air at about 800° Fahr.; and in the second 18 cwt. of coke was the assumed consumption, and the deficiency of heat was made up by conferring additional heat on the blast.

21 cwt. of coke was equal to 20 cwt. pure carbon; of this, 6 cwt., or thereabouts, burnt to

Carbonic acid, would afford	48,000	cwt. heat units.
14 cwt. burnt to carbonic oxide	33,600	„ „
Blast would contain about	11,400	„ „
Total . . .	93,000	„ „

The above weights of carbon converted into carbonic acid and carbonic oxide afforded these two gases volumetrically, as 43 of the former to 100 of the latter; which, according to his experiments, under the circumstances, exhibited about the neutral position in regard to reduction of iron oxide.

Reducing now the coke to 18 cwt. for each ton of iron, representing in round numbers 17 cwt. of pure carbon, then

6 cwt. of carbon burnt to carbonic acid gave, as before .	48,000 units.
11 „ „ „ carbonic oxide	26,400 „
Leaving the blast to supply	18,600 „
Total, as before. . . .	93,000

In the latter case, however, the proportion of carbonic acid to carbonic oxide was as 55 volumes of the former to 100 of the latter, which constituted an extent of saturation with oxygen impossible to be maintained when smelting the Cleveland ironstone.

It had been alleged that by raising the temperature of the blast from 1,000° to 1,442° Fahr., the consumption of coke had been reduced from 24 to 20 cwt. per ton of iron; when using the same quality of coke, similar ore, the same pressure of blast, and he presumed he ought to have included the same quality of atmosphere. Now, it was most difficult to secure this perfect identity; but, irrespective of this, he maintained that in a perfect furnace, the consumption of fuel with air at about 900° Fahr. was a mere fraction above 21 cwt., and ought never to amount to 24 cwt. of best Durham coke. But if the improvement had been due solely to the heat in the blast, he fancied that a difference of nearer 1,000° than 442° would have been needed.

The results obtained at Consett, which results were, in the frankest possible manner, furnished to Mr. Bell, had been quoted in the course of the discussion. It was said anything could be proved by figures, and if ever there was a case in which this could be truly applied it was in the working of blast furnaces. Now it was clear in the long run if a higher temperature in the blast possessed the virtue claimed for it, then there should be, as a rule, a saving of coke as the temperature of the blast was increased. He therefore took nearly a year's workings of a furnace using superheated air—always, it was stated, using similar minerals and similar fuel. The temperatures were placed in a column in the order of their intensity, beginning at the lowest. If Mr. Whitwell was absolutely correct, then the coke consumed should be lowest

when the temperature of the air was highest, and *vice versâ*. The following table showed that this was not so:—

AVERAGE TEMPERATURES under 1150° Fahr.—Fifteen weeks.

Temp. Fahr. °	Coke per Ton Iron. cwt.	qrs.	lbs.	Iron made. Tons.
1061	22	0	14	460
1098	18	0	21	484
1106	22	3	12	455
1112	18	2	26	465
1122	17	2	17	477
1126	19	0	3	513
1132	19	1	20	532
1133	20	2	15	437
1133	19	2	26	452
1134	17	0	18	467
1140	20	1	6	447
1144	19	0	19	435
1145	19	2	9	488
1148	19	2	13	491
1149	19	1	18	483

Average.

Temp. Fahr. °	Coke per Ton. cwt.	qrs.	lbs.	Iron. Tons.	Yield Ore. Per Cent.
1125	19	2	8	472	45·63

TEMPERATURES between 1150° and 1200° Fahr.—Sixteen weeks.

Temp. Fahr. °	Coke per Ton Iron. cwt.	qrs.	lbs.	Iron made. Tons.
1152	18	3	4	537
1158	19	1	25	476
1170	19	1	19	543
1172	18	3	20	539
1173	19	0	1	483
1174	19	3	23	455
1176	19	2	10	507
1177	19	3	22	415
1178	19	0	19	476
1181	19	1	27	462
1183	22	3	7	201
1183	19	3	24	491
1184	20	2	1	455
1184	19	1	1	456
1194	19	1	26	495
1199	19	1	9	503

Average.

Temp. Fahr. °	Coke per Ton. cwt.	qrs.	lbs.	Iron. Tons.	Yield Ore. Per Cent.
1177	19	2	4	468	46·27

TEMPERATURES between 1200° and 1250° Fahr.—Twelve weeks.

Temp. Fahr. °	Coke per Ton Iron. cwt.	qrs.	lbs.	Iron made. Tons.
1201	18	1	24	506
1201	19	0	13	577
1208	20	2	23	465
1208	19	0	21	470
1208	18	3	14	462
1219	19	0	22	510
1230	19	0	26	511
1236	18	3	3	470
1236	20	2	1	478
1236	19	0	19	478
1243	19	3	19	482
1245	20	1	19	468

Average.

Temp. Fahr. °	Coke per Ton. cwt.	qrs.	lbs.	Iron. Tons.	Yield Ore. Per Cent.
1221	19	24		491	46·41

TEMPERATURES 1250° Fahr. and above.—Four weeks.

Temp. Fahr. °	Coke per Ton Iron. cwt. qrs. lbs.	Iron made. Tons.
1260	19 1 18	484
1283	20 0 20	508
1292	17 2 8	431
1316	19 2 4	504

Average.			
Temp. Fahr. °	Coke per Ton. cwt. qrs. lbs.	Iron. Tons.	Yield Ore. Per Cent.
1288	19 0 19	457	45·49

He did not deny that the application of superheated air had been most beneficial at Consett, but it was applied to furnaces of an imperfect character; he meant as regarded size, and therefore power of saturating the gases with oxygen. It was alleged, and probably rightly so, that the materials were unmanageable in a very high furnace, say 80 feet, and consequently Mr. Whitwell had to be content with a furnace 55 feet high; and here, as with Neilson, who greatly improved the action of a small furnace by using air at 600° Fahr., Mr. Whitwell added to the power of a furnace of moderate dimensions at Consett by using air at 1,100° or 1,200° Fahr. instead of 800°, with which it was compared. Mr. Smith said he found an improvement by raising the temperature of the air from 700° to 1,100° Fahr., but more when he raised it to 1,500°, and this, it was alleged, was a proof that his doctrine was erroneous. But Mr. Smith was working with a less capacious, and therefore a less perfect furnace than those used in Cleveland, and was compelled to do so from the nature of the Lancashire ore. Mr. Whitwell then proceeded to state that a furnace 85 feet high, with a bosh of 26 feet, in Cleveland, had been consuming 24½ cwt. of coke per ton of iron. Mr. Bell could not be answerable for the improper working of any particular furnace, for 24½ cwt. was far too large a quantity of fuel with air heated to 900° Fahr. Against this he would quote two works using similar material in furnaces 80 feet high and upwards. At one the air was heated to 1,100° or 1,250° Fahr., and at the other at from 800° to 900° Fahr. The consumption of coke at the two corresponded within $\frac{1}{10}$th of a cwt. per ton of produce. Mr. Whitwell spoke of the temperature in the works at Middlesbrough being usually 1,100°; if so, what Mr. Bell called 900° others called 1,100°. He often heard of these high temperatures, and yet they rarely were capable of fusing antimony, which melted at 842° Fahr. Professor Forbes objected to the supposition that in the blast furnace perfection had been nearly approached in the coke consumed, for such a supposition was tantamount to retrogression. But Dr. Forbes could not pretend that a chemist who warned the chemical manufacturer that it was in vain for him to enlarge his plant or expend money in the hope of getting more than

49 lbs. of oil of vitriol from 16 lbs. of sulphur, was performing a useless duty; and what had been done for the maker of vitriol he had attempted to accomplish for the iron-maker. He did not attempt in so complicated a question to draw a hard line, but the opinions to which he had given expression were the result of lengthened examination and experiment, confirmed by considerable experience at the furnace itself. Professor Forbes dwelt on the probability that he was incorrect in some of the figures constituting the duty of the blast furnace. He believed this was not very material for the general argument, for although in some cases there existed much difficulty in determining the exact quantity of heat absorbed, he thought there was presumptive evidence of their general correctness. He had examined the heat development based upon the state of oxidation and quantity of carbon burnt, varying from 15 to 30 cwt. per ton of iron, smelting ores yielding from 40 to 60 per cent. of metal. The limestone consumed was sometimes 18 cwt. per ton of iron, and sometimes it was entirely absent. Thus the factors varied considerably, and yet the final results corresponded very closely, showing, he submitted, a fair approach to general truth.

With regard to the shape of the furnace alluded to by Professor Forbes, the case of copper ore afforded no light on the question under discussion. In an iron furnace it was not mere fusion which had to be dealt with, but a complicated series of chemical reactions which were not analogous to those in copper smelting. He was quite aware of the importance of shape in a blast furnace; but he maintained that when the gases were as fully oxidized and cooled as the process would admit of, no mere change of shape could effect further good. His opponents should now apply their minds to proving that the relation of carbonic acid could be made to exceed the proportions mentioned by him, instead of dealing in general statements about the size of the furnace, its shape, or the temperature of the blast. It must not be supposed that he pretended that some modification of the process of smelting an ore of iron might not be attended with economy in the quantity of fuel consumed; it must be distinctly remembered the discussion was on the process as it was now carried on, and whether there were limits in size of furnace, or in temperature of blast, under present conditions of the process, which it was useless to exceed.

Before concluding he would observe, in reference to the heat of the blast, that his remarks had exclusive reference to the possibility of employing a furnace of such dimensions as to render it unnecessary to raise this beyond that which was usually obtained

in the ordinary stoves, say 800° or 900° Fahr. There were many cases in which superheated blast had been highly advantageous, as, for example, when circumstances prevented the use of very large furnaces, as at Consett and elsewhere. Taking, however, the fire-brick stove, as proposed by Mr. Cowper, or modified by Mr. Whitwell, it was an admirable form of apparatus, inasmuch as by its use the least possible amount of friction was opposed to the passage of the blast, loss of air was practically avoided, and, in addition, it possessed manifest advantages in point of durability.

March 26, 1872.

T. HAWKSLEY, President,
in the Chair.

The Discussion upon the Paper No. 1,328, "On the Limit of Economy of Fuel in the Iron Blast Furnace," by Mr. I. Lowthian Bell, was continued throughout the meeting.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously, "That, in order to insure a fuller attendance of members than could be obtained on Easter Tuesday, the meeting be adjourned until Tuesday evening, the 9th of April."

April 9, 1872.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—
Sir John Gay Newton Alleyne, Bart., John Robinson, and Edward William Young, as Members; James Smyth Benest, Joseph Bray, Joseph Cash, Stud. Inst. C.E., Edmund Compton, Robert Edwards, William Forrest, Antonio Gabrielli, John Joseph Grinlinton, Captain George Lane Cockburn Merewether, R.E., Berkeley Paget, Richard Steven Roper, George Hennet Ross, Arthur Henry Whipham, Frederick Anthony White, Leedham White, Sir Frederick Martin Williams, Bart., M.P., William Lloyd Wise, and Samuel William Worssam, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VIII., of the Bye-Laws, had transferred George James Crosbie Dawson and George Wilson from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—George Barclay Bruce, Jun., Ernest William Enfield, Mark Helmore, Edward Jennings, Philip Townshend Somerville Large, Robert Edward Peake, and Herbert Perkins Vacher.

The Discussion upon the Paper No. 1,326, "The Soonkêsala Canal," by Mr. J. H. Latham, was continued throughout the meeting.

April 16, 1872.

T. HAWKSLEY, President,
in the Chair.

No. 1,316.—"Description of the new South Dock in the Isle of Dogs, forming part of the West India Docks." By Leveson Francis Vernon-Harcourt, M.A., M. Inst. C.E.

The East and West India Dock Company determined, in 1866, to increase their already large system of docks, by reconstructing and enlarging the south dock, formerly known as "the City canal." This canal was constructed in the north of the Isle of Dogs, at the beginning of the present century, by the City authorities, for the accommodation of shipping coming up the Thames, and to enable it to avoid the great bend in the river, between Blackwall and Limehouse, round the Isle of Dogs. At each extremity of the canal, at its junction with the river, there was a lock, about 45 feet wide, 190 feet long, and with sills 23 feet 6 inches below Trinity high water. The canal does not appear to have been much used for the purpose for which it was intended, and was purchased by the West India Dock Company, who constructed a timber pond to the south of, and communicating with, the City canal. Since it became the property of the West India Dock Company it was called the "South Dock," lying, as it did, to the south of the import and export docks belonging to that company. It is upon the site of the City canal, the timber-pond, and adjacent land, that the new South Dock has been constructed. The City canal had merely sloping banks on each side, and no quay walls, and, consequently, was not convenient for the purposes of a dock.

The new South Dock (Plate 18) was constructed in accordance with designs furnished by Mr. Hawkshaw, Past President Inst. C.E., and under his direction, the Author being the Resident Engineer. Mr. George Wythes, Assoc. Inst. C.E., was the contractor for the whole of the work, and Mr. John Baldwin acted as Mr. Wythes' agent.

The works consist of a dock having an area of $26\frac{3}{4}$ acres, joined to a basin of $5\frac{1}{4}$ acres, by a passage with reverse gates. The west entrance to the City canal was retained, but at the eastern extremity a new entrance has been constructed, leading from the river to the basin. On the south side of the dock, foundations for

five warehouses have been built, and the superstructure erected on three of them, with a quay shed in front.

Dock.

The main dock, is 2,650 feet long, 450 feet broad, and has quay walls all round it. The bottom of the dock, which is covered throughout with a layer of puddle 18 inches thick, is 29 feet below Trinity high water, and the surface of the quay is 5 feet 10½ inches above the same level. On the north side of the dock there are sixteen jetties, affording accommodation for thirty-two vessels, and opposite each jetty, down the centre of the dock, are buoys for mooring the vessels.

Dock Walls.

The dock walls, Plate 19, Figs. 6 and 7, are composed partly of brickwork and partly of concrete; the foundations consisting of concrete, varying in thickness according to the nature of the soil. Upon the concrete foundation front, cross, and back walls were built of brickwork, the intermediate pockets being filled with concrete. The front wall is 3 feet 6 inches thick, and the cross walls are 2 feet 4 inches thick, and they are tied together with hoop-iron bond, the cross walls being 10 feet apart from centre to centre. The back wall is only 14 inches thick, its chief use having been to keep the concrete in place till it became consolidated. The walls were built up about 4 feet 6 inches at a time, and the pockets then filled with concrete, to the level of the walls, before another stage was commenced. Lias lime was used in the concrete and mortar up to 6 feet above the foundations; for the remainder of the wall grey-stone lime was employed. The face-work is built with best picked London stock bricks, and the rest of the brickwork with ordinary stock bricks. The wall is coped throughout with Bramley Fall stone, 18 inches thick, and 3 feet wide, dowelled with slate dowels, 4 inches square, run in with Portland cement. The batter of the face of the walls is 1 in 24.

Jetties.

The jetties Plate 21, Figs. 1 and 2, are 130 feet long, and 25 feet wide, and are of Baltic timber. They are formed of upright timbers fixed to horizontal cills, strutted diagonally, and connected, by longitudinal and transverse walings, with longitudinal joists at the top, covered with a floor of planking 4-inches thick. The sides and ends of the jetties are protected with vertical fenders of American white rock elm.

West Entrance.

At the western end, the dock has communication with the river by means of the old entrance to the City canal, which has been retained, being sufficiently large for the accommodation of small craft and barges. As, however, the sills of the old lock are 6 feet higher than the bottom of the dock, a row of sheet piling was driven across the end of the old lock, where it joins the dock, to prevent the sills being undermined, and the ground was sloped from the top of the sheet piling, at the level of the bottom of the lock, down to the dock bottom, the slope being protected by Bramley Fall pitching.

Passage.

The dock is separated from the basin by a Passage (Plate 19, Figs. 1 and 2) which, being constructed with two pairs of reverse gates, allows the level of the water, either in the dock or in the basin, to be raised or lowered independently of one another. This is important for the satisfactory working of the two entrances, as high water does not occur at both at the same time. The passage is 176 feet long, and 55 feet wide. The foundations of the walls and of the floor of the passage consist of concrete, varying in thickness, and carried to a depth of 13 feet below the bottom, under the sills and walls of the dock, and in line with the sills for 17 feet in width. The heel-post stones, the hollow quoins, and the sills are of granite; the remainder of the stonework is of Bramley Fall. The gate floors and aprons are on a level with the bottom of the dock and basin, and the level of the sills is 2 feet higher, or 27 feet below Trinity high water. The bottom of the passage is paved with ashlar masonry, 2 feet 6 inches thick at the gate floors, and 2 feet thick elsewhere, except at each end, where a course of headers and stretchers are carried right across, 3 feet in thickness. The walls of the passage are composed of solid brickwork, with the exception of the portion forming the foundation of the swing-bridge over the centre of the passage, where concrete has been introduced. There are two capstans at each end of the passage for hauling the vessels through it.

Gates.

The gates in the passage, Plate 19, Figs. 3, 4, and 5, are of iron, with the exception of the heel-posts, meeting posts, and sill pieces, which are of greenheart timber. The gates are cellular, having two skins, formed of iron plates, separated by, and rivetted to,

horizontal and vertical ribs; the skins which form the sides of the gates are curved outwards, but the sill-piece is straight, to fit the sill. The sill consists of two straight lines meeting at a point in the centre of the passage, and making an angle of 126° between them; the curves of the sides are arcs of circles whose radii are 60 feet and 120 feet. The heel-post works on a steel pivot let into the heel-post stone, and there is a roller fixed to each gate, at a distance of 26 feet 8 inches from the heel-post, running on a cast-iron roller-path, to assist in bearing the weight of the gate. The gates are secured at the top to the walls by strong iron anchors let into the masonry. The gates were manufactured by Messrs. Eastons and Anderson, from designs furnished by Mr. Hawkshaw, this portion of the work having been sublet to them by Mr. Wythes. Each gate was erected on the gate floor, only a few feet from its ultimate position, and was tested by being filled with water. After being moved into their places, sufficient water was introduced to counter-balance their tendency to float. There are three sluices at the bottom of each gate, for adjusting the levels of the water in the dock and in the basin. The gates are opened and closed by means of chains, passing over cast-iron rollers fixed in roller-boxes at the bottom of the chain passages. The roller-boxes fit into grooves in the chain passages, and are so arranged that they can be readily drawn up for repairs.

Basin.

The passage joins the dock to a basin, 600 feet long, 370 feet wide, and is surrounded by a quay wall, precisely similar to the dock wall previously described. On the north side, the basin is connected with the south entrance of the Junction Dock, thereby making a communication between the South Dock and the rest of the West India Docks. The principal object of the basin is to serve as an immense lock during a rising tide, the water level being drawn down to that of the river when the tide has risen sufficiently. The gates between the basin and the river are then opened, and the vessels are brought into the basin from the river, or *vice versâ*, until high water, when the gates are closed, and the vessels in the basin can be passed into the dock at leisure. By this arrangement the water in the main dock can be kept at a constant level.

East Entrance Lock.

The lock, forming the east entrance from the Thames near Blackwall into the City canal, was not sufficient, either in width or

in depth, to admit the class of vessels for which the new South Dock was designed. A new east entrance lock has therefore been built, (Plate 20), connecting the basin of the South Dock with the river. The length of the lock between the gates is 300 feet, and the width is 55 feet. The bottom of the lock between the gates consists of a segmental brick invert, 3 feet thick, laid on a concrete foundation, with springing stones of Bramley Fall. The gate floors, and aprons outside the gates, consist of ashlar masonry of Bramley Fall, laid on concrete foundations, the masonry being bedded in lias lime, and grouted with Portland cement. The foundations under the sills are precisely similar to those under the sills in the passage. The new entrance lock being built upon the site of the old lock, advantage was taken of the north wall of the old lock, which was left standing, and the north wall of the new entrance lock was built of solid brickwork, 9 feet thick, in front of it. The south wall of the old lock had to be removed, but so solid was the old brickwork that blasting had to be resorted to. With the exception of the north wall between the gates, and the portions of the walls where the sluices are situated, the walls are similar to the dock walls; only outside the outer gates the pockets of concrete are not carried up from the bottom, but the walls are built of solid brickwork to 16½ feet above the foundations, to increase the strength at this place, where the pressure in front is constantly varying with the rise and fall of the tide, and where the walls are not supported, as they are between the gates, by an invert.

For the purpose of emptying and filling the lock, and also for lowering the level of the water in the basin, there are sluices in the walls, on each side, at both pair of gates, in addition to the sluices in the gates themselves. The inlets to each sluiceway are four in number, placed in the gate recesses and on a level with the gate floors. These open into the main sluiceways, which are 5 feet wide, 7 feet 6 inches high, arched at the top, and lead to the outlets, two in number, in the invert on each side, and close together. Beyond the entrance gates there are four outlets on each side, distributed along the walls so as to serve for clearing away any mud which may accumulate on the apron. The main sluiceways are lined with Staffordshire blue bricks; the sides and tops of the inlets and outlets are of Bramley Fall stone, the bottoms of the sluiceways throughout are paved with it, and the grooves for the shuttles, of which there are two in each sluiceway, are lined with the same material. The gates, sills, hollow quoins, and chain passages are precisely similar to those in the passage already described.

Beyond the walls, on the north and south sides of the entrance, and connected with them, are timber jetties, composed of pilework firmly connected by struts and walings, and planked on the top; the southern one being for vessels to lie alongside till they can enter the lock, and the northern one to assist the outgoing vessels in bending their course down the river, which is at right angles to the entrance.

On the north side of the lock, and about the centre of it, are the foundations supporting the new roadway swing-bridge crossing the lock, the old bridge having been removed in widening the lock. The bridge is for a carriage-way and footpaths on each side, and is similar in construction to the railway bridge hereafter to be described, Plate 21, Figs. 3 to 12.

Accommodation had also to be provided for the gas and water-pipes supplying the Isle of Dogs. This was effected by two grooves in the invert, and a vertical shaft on each side in the walls, large enough to afford access to the pipes in case of accident. There are capstans on both sides at the ends of the entrance, to assist in drawing vessels through the lock; the quays also are well supplied with mooring and check posts.

Warehouses.

The foundations for the warehouses (Plate 18), were built on the south side of the new dock; and, as the original surface consisted of made ground and mud on the site of the old timber pond, the foundations were in every case carried down to gravel. Two jute warehouses, and one warehouse three stories high, with a basement, have been erected on these foundations. A quay shed and cranes have been erected in front of the warehouses, for protecting and facilitating the unloading of goods.

Blackwall and Millwall Extension Railway.

An Act was passed in 1865, authorizing the construction of the Blackwall and Millwall Extension railway. By the stipulations of that Act, the East and West India Dock Company had permission to construct and control that part of the railway which passed through their land. This portion of the line was accordingly carried out during the period of the execution of the other works. It enters the property of the East and West India Dock Company soon after starting from the Blackwall railway, between the West India Docks Station and the Poplar Station, and, passing over the locks leading from the import and export

docks of the West India Docks into the Blackwall Basin, enters the Millwall Dock Company's property soon after crossing the passage between the south dock and basin. Thus, in this short space, three swing bridges had to be constructed. The two over the Blackwall basin locks were for two lines of way; one, for the use of the East and West India Dock Company, branching off to the north quay of the south dock; the other, belonging to the Blackwall and Millwall Extension railway, going over the passage bridge, which was therefore only constructed for one line of way. The width of the Blackwall basin locks is 43 feet; but, as the line crosses the locks on the skew, the length of the portions of the bridges spanning the locks had to be made 66 feet 6 inches, and 80 feet respectively between the pivots and the ends. The largest of these is shown on Plate 21, Figs. 3 to 12, and indicates the form of construction adopted for all the swing bridges.

The bridges were carried into execution by the Park Gate Iron Company, under the direction of Mr. Joseph Phillips, Assoc. Inst. C.E.; and the new roadway swing bridge over the east entrance lock formed part of the same contract.

Hydraulic Machinery.

The whole of the swing bridges, gates, capstans, shuttles, and cranes are worked by hydraulic machinery, supplied by Sir W. G. Armstrong and Co. In order to furnish the increase of power required for working these machines, besides those already in operation, additional engines and boilers were erected at the engine-house at the West India Docks. A second accumulator was put up at the same place, and another at the eastern end of the warehouses on the south side of the new dock, the water being conveyed to the dock in 5-inch pressure pipes. The pipes cross the dock in front of the Limehouse lock, are carried along the back of the south walls of the dock and basin to the machines and accumulator house, and cross also the passage and entrance lock to supply the machines on the northern side.

The works were commenced in October, 1866, when a cofferdam was made across the opening between the timber pond and the canal. The water was then drawn off from the timber pond, so that the foundations of the warehouses and the excavation for the new dock could be proceeded with before the water was excluded from the canal. A cofferdam was begun at the same time across the canal, between the entrance to the Junction Dock and the site of the present passage, as the new east entrance lock did

not form part of the original contract, and it was desirable to leave the portion of the canal, east of the Junction Dock entrance, open for a time, so as to have water accommodation for unloading materials for the works. Had the Dock Company given at the first their sanction for carrying out the whole of the works ultimately executed, this cofferdam might have been dispensed with, and the works finished in a shorter time.

In July, 1867, the foundations of the warehouses were completed, the tide was excluded from the canal, and the greater part of the water in it run off at low water through sluices in a cofferdam constructed across the west entrance lock; and at the same time the foundations for the south wall of the dock were laid. In August the cofferdam on the river side of the old eastern entrance lock was commenced; it formed an arc of a circle of 150 feet radius, and was composed of a double row of piles separated by an interval of 5 feet, which was filled with clay, the sides of the cofferdam being strengthened with laminated walings, composed of 3-inch planks. Considerable difficulty was experienced in driving the piles, owing to the hard nature of the ground a few feet below the surface, a stratum of natural concrete having been probably formed by the mixture of gravel, sand, and shells, such as was met with in other places on the work, through which the sheeting piles, though fitted with heavy cast-iron shoes, were in most instances unable to penetrate. Notwithstanding this hindrance, and the fact that the Board of Works excavated a trench for laying the pipes for the Metropolitan drainage close in front of the cofferdam immediately after it was finished, the cofferdam stood remarkably well, and the leakage through it was inconsiderable.

Soon after the dock-walls had been commenced, the influx of water into the foundations was greatly increased by the filling of the adjacent Millwall Dock, from which the water percolated through the porous gravel into the dock excavations. To keep down the water it was necessary to employ three pumps, capable together of lifting about 10,000 gallons per minute; and occasionally a centrifugal pump capable of raising about 1,500 gallons per minute was also worked. The dock and basin were carefully puddled throughout, to prevent leakage when they were filled with water; this provision was especially necessary owing to the low level at which many of the adjacent houses in the Isle of Dogs are built.

The foundations of the walls rest partly on gravel, and partly on stiff blue clay, mixed in some places with a good deal of sand. Along a portion of the site of the north wall of the dock, such a

firm and thick bed of conglomerate was found, that the concrete foundation was dispensed with, and the wall was laid on the conglomerate. The ground, through which the dock excavations were carried, consisted chiefly of a thick bed of gravel and sand in varying proportions, and averaging about 20 feet in thickness. Underlying the gravel a layer of blue clay was met with, which, as ascertained by borings, in no case attains a greater thickness than 9 feet on the site of the dock, and towards the western end dies out altogether, thus appearing to form the extreme limit of the London clay in this direction. A portion of the earth from the excavations was conveyed away in barges; another portion was employed in raising the adjacent low ground belonging to the Dock Company, and the remainder was tipped on adjoining lands which were considerably below Trinity high-water mark. The first stone of the passage was laid on the 4th of April, 1868, when considerable progress had been made with the dock walls and excavations. In June, 1868, the cofferdam outside the east entrance lock having been completed, the water was removed from the second portion of the works, comprised between the river and the cofferdam near the passage, the junction dock-gates having been strutted, to assist them in resisting the full pressure of water to which they were then subjected, and to avoid risk of accident. From this period the whole of the works were proceeded with simultaneously.

On the 5th of November, 1869, the dock walls and excavation being completed, and the gates of the passage finished, water was let in from the river through a sluice in the cofferdam at the western entrance; in December, water was admtted into the basin and east entrance lock through sluices in the junction dock-gates; in January, 1870, the new roadway bridge was opened for traffic, and the temporary bridge removed; and on the 5th of March, 1870, the dock was formally opened by the Chairman of the East and West India Dock Company.

Cost of Works.

The cost of the several works above described was as follows, viz.:—

	£
Dock, Basin, Passage, East Entrance Lock, and Warehouse foundations	467,639
Warehouses	60,000
Blackwall and Millwall Extension Railway, portion within East and West India Dock Company's boundaries . .	24,500
Hydraulic machinery	19,000
Total	571,139

As all the works were carried out within the limits of the property belonging to the East and West India Dock Company, no Act of Parliament was required, and no expense was incurred in the purchase of land.

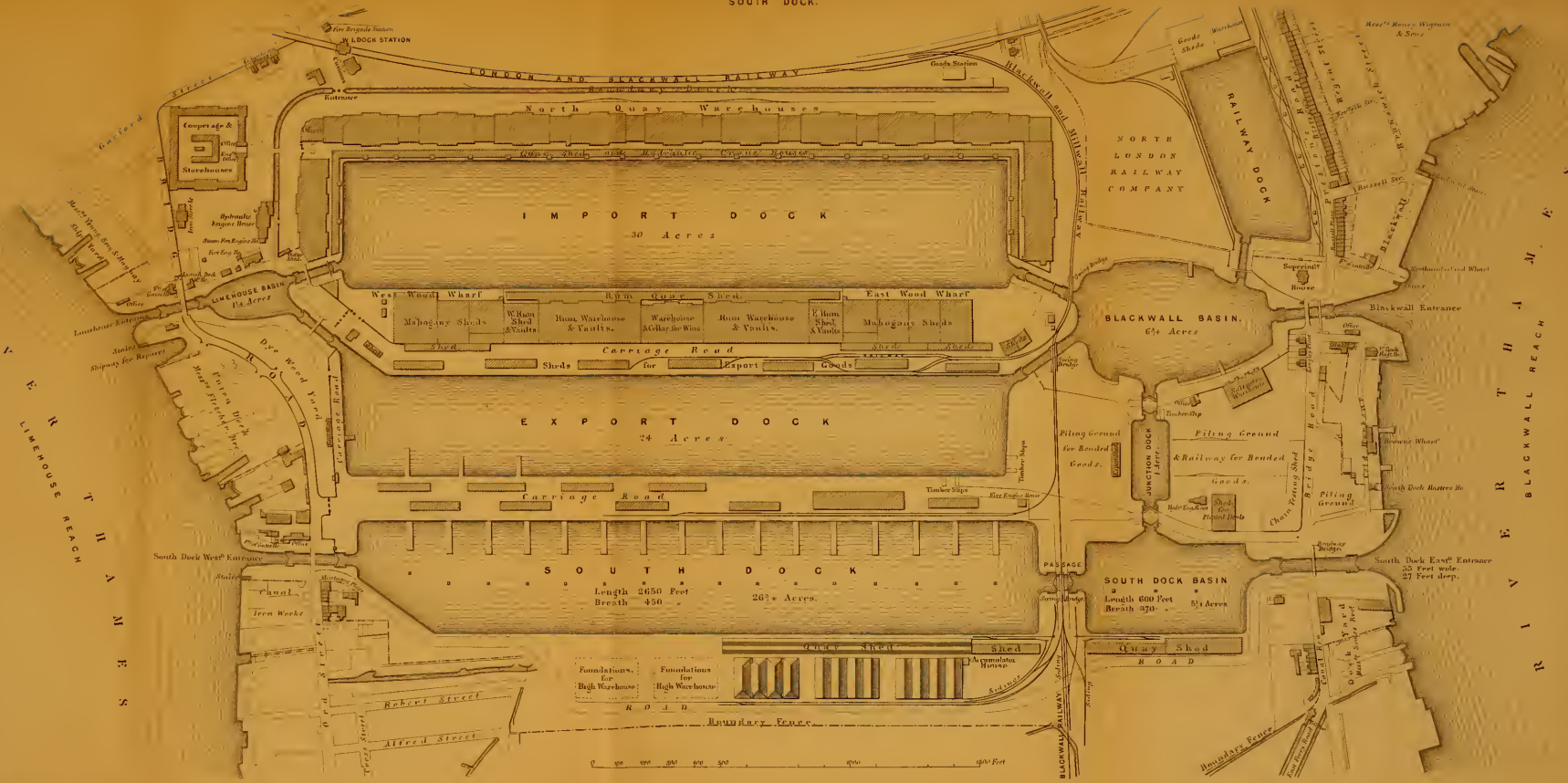
With regard to the question of cost, the Author wishes to direct attention to that of the dock wall, an item which forms so large a portion of the expense in the construction of a dock. The dock wall, as constructed, cost only £12 2*s.* per lineal foot, which, the Author thinks, will compare favourably with other dock walls. This small cost was chiefly due to the large employment of concrete in its construction, which, in consequence of sand and gravel being found in abundance in the excavations, was much cheaper than brickwork.

The communication is accompanied by a series of drawings and diagrams, from which Plates 18, 19, 20, and 21, have been compiled.

[Mr. Redman

WEST INDIA DOCKS.

SOUTH DOCK.

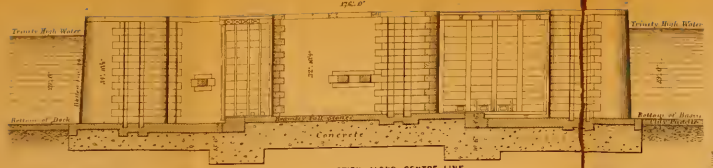


WEST INDIA DOCKS.

SOUTH DOCK.

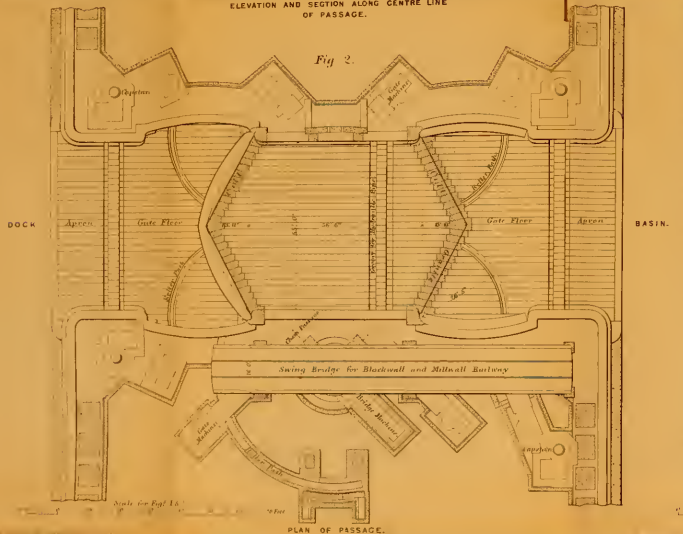
PLATE 13

Fig 1.



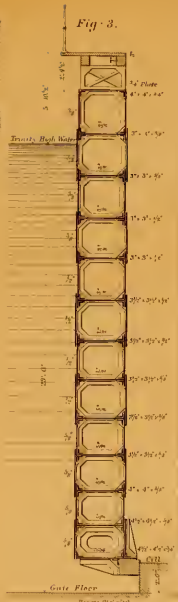
ELEVATION AND SECTION ALONG CENTRE LINE OF PASSAGE.

Fig 2.



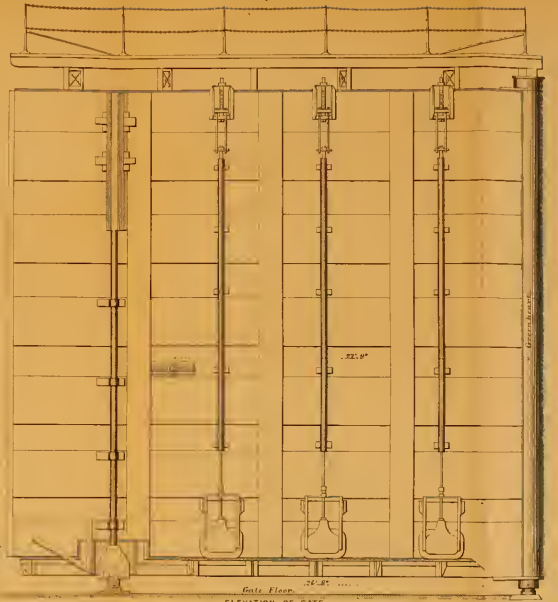
PLAN OF PASSAGE.

Fig 3.



VERTICAL SECTION OF GATE.

Fig 4.

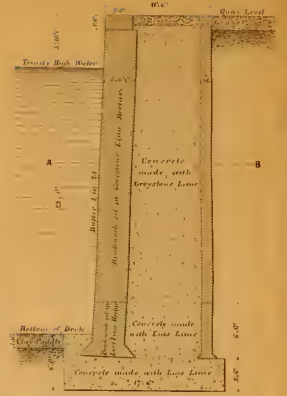


ELEVATION OF GATE

Fig 5.

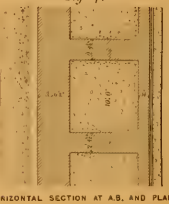
HORIZONTAL SECTION AND PLAN.

Fig 6.



VERTICAL SECTION OF DOCK WALL

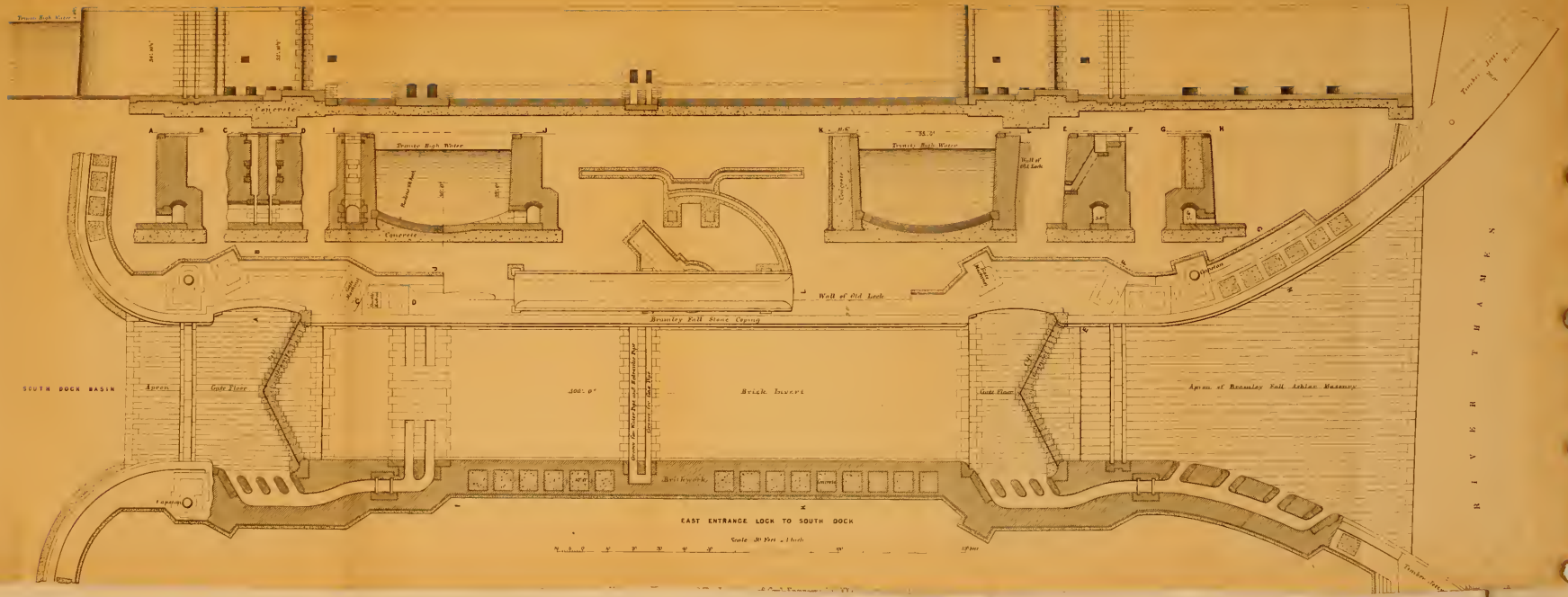
Fig 7.



HORIZONTAL SECTION AT A.B. AND PLAN.

WEST INDIA DOCKS.

SOUTH DOCK.



WEST INDIA DOCKS.

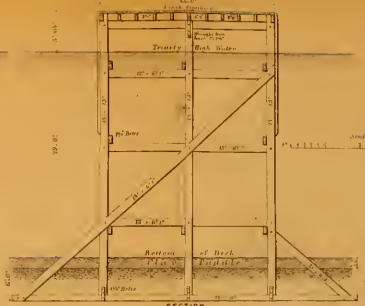
SOUTH DOCK.

PLATE 21

Fig 1.

ELEVATION OF JETTY.

Fig 2

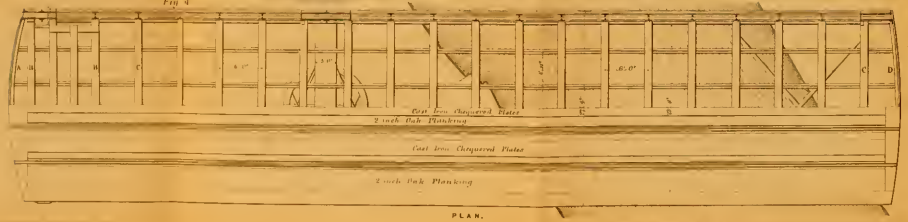


SECTION.

Fig 3.

ELEVATION
SWING-BRIDGE OVER LOCK BETWEEN BLACKWALL BASIN AND EXPORT DOCK.

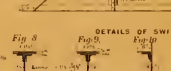
Fig 4



PLAN.

DETAILS OF SWING-BRIDGE.

Fig 7 Fig 8 Fig 9. Fig 10

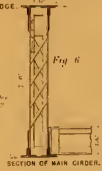


CROSS GIRDERS.

Fig 5.

HALF SECTION OF BRIDGE NEAR PIVOT.

Fig 6



SECTION OF MAIN GIRDER.

Fig 11.

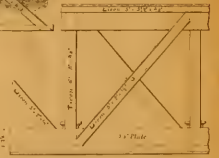
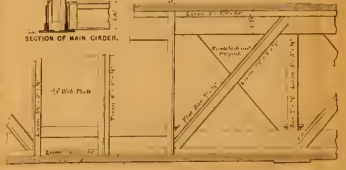


Fig 12.



Mr. Redman said the West India Docks were remarkable in the history of the port of London as being one of the most successful engineering and commercial enterprises of the period. At the present day, it was hardly possible to realise the fact, that the docks of the port of London did away with the system of loading and unloading in the stream, which gave rise to so much pillage and loss in the earlier part of the present century. The whole of the West India system of docks, as an engineering design, was admirable in several respects. It had deep-water approaches on both sides. The docks were constructed upon comparatively open land at a very low cost, compared with the London and St. Katherine's Docks higher up the river. That might account for the favourable position which the West India Docks had always occupied. Starting with a capital of £500,000, which had gradually been increased to over £3,000,000, the stock of the company had yielded an interest of 6½ per cent., with large bonuses in addition.

The West India Docks were originally planned by Mr. Ralph Walker, the uncle of the second President of the Institution, who, prior to the inquiry into the condition of the port of London, was the commander of a West India merchant ship. After the age of forty he remained at home, and sent his ship out under another commander for the purpose of testing an improvement in the mariner's compass, while he directed his attention to the formation of docks in London. He was examined before the committee in 1798, and, with Mr. Jessop, was joint engineer of the West India Docks, and also carried out the East India Docks and the London Docks in part.

The City Canal, on the site of which the work just described was developed, was constructed by the Corporation, and was purchased by the West India Dock Company. The canal shortened the navigable distance of the river round the Isle of Dogs, but the lockage was found a heavy tax, and no great gain in time accrued. It was consequently adopted by the Dock Company, and turned into a dock for empty vessels. The company also constructed a timber pond on the south side of the canal, which was afterwards extended, and had always formed an admirable adjunct to the docks. The subsequent additions to the West India Docks were not remarkable.

The dock to the north of the Blackwall basin was formed into a collier dock on the site of the reservoir for the supply of water to the dock, which was not much used during the time Mr. Martin was the engineer of the dock. After the construction of that dock a failure took place in the long wing wall of the Blackwall entrance of the West India Dock, which was ascribed by some to

the fact of the dock not being puddled, and the water getting under the foundation of the wall. The desirability then of effecting a communication between the Blackwall basin of the West India Docks and the eastern end of the City canal, was to make the two Blackwall locks common to the docks, was mooted, and the basin between the West India Docks and the City canal was constructed under the auspices of the late Mr. Rendel. The basin was of small area but of great depth. It had a lock at each end, and was formed in an alluvial deposit containing much water. Being of so confined an area, it was a very troublesome and costly work. It was carried out by the late Mr. Brassey; but it might be looked upon to a certain extent as a superfluous work as it was only occasionally used.[1] The original timber swing bridges spanning the entrances were of the same type as the cast-iron bridges that succeeded them, and were worked by the same description of machinery as those which followed.

He had watched the progress of this work, and could testify to the admirable manner in which the roads were driven through this large area of excavation, and in which the material was drawn out and the drainage led to one common pumping sump. The item of pumping, compared with the small basin he had spoken of, was very light. He believed the importance of this extension of the West India Docks had been shown by the fact, that it had already drawn a considerable amount of traffic from the London Docks. The original works of the West India Docks were simple in design, and most admirably executed, and he did not think any portion of them showed symptoms of failure. He believed they had admirably carried out all the purposes for which they were planned, and he thought they quite deserved the commendation which was bestowed upon them by Baron Dupin.[2]

The low cost of these works was one of the sources of their commercial success. Higher up the river the docks were constructed in densely populated neighbourhoods, where houses had to be levelled for the purpose. In the case of the London and the St. Katherine's Docks the cost was from £30,000 to £50,000 per acre of water area. Taking the water area of the West India Docks and

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[1] Mr. Redman exhibited an isometrical view of the establishment soon after the docks were opened, which he subsequently presented to the Institution.—Sec. Inst. C.E.

[2] *Vide* "The Commercial Power of Great Britain," vol. ii., p. 43. 8vo. London: 1825.

their capital stock, it would be found that the cost per acre of water area, exclusive of the addition under discussion, was only about £15,000 per acre. The approaches from the river were now as free almost as on the day when the works were constructed: there was always easy access to them; whereas the opposite was the case with the London and the St. Katherine's Docks.

A few years ago he presented a Paper to the Institution on the dock entrances of the Port of London,[1] pointing out their advantages and disadvantages, and suggesting a certain outline of form to facilitate the entrance and departure of vessels. No doubt the form adopted for the entrance of this dock was very admirable in that respect; because the long trumpet mouth and straight quay face gave great facilities in docking vessels. The stern of the ship being driven up against the upper wing placed her in a lie-by out of the tide, and great facilities for leaving the dock under way and being taken down by the tide were given by the lower wing projecting down stream. No doubt the quays were very economical, and they bore the evidence of that economy on the face of them; but hereafter, at the quoins, either fender piles or something of the kind would probably be found necessary; though the reply to that remark might be that the interest upon the outlay—the saving in that respect—was sufficient argument in favour of the cheaper construction. In the original works the walls of the West India Docks throughout the establishment were faced with ashlar between wind and water. The lock gates he had not seen in action, but they appeared to be simple in form and admirably adapted for their purpose.

Mr. A. Giles said he regretted that the Author had made the Paper so concise. The dock wall was on a plan which had been adopted in principle by his father thirty years ago. He made the face of brickwork, and thin walls of brick to act as pockets for the concrete; and he had himself built walls of the same character, but with a more extensive use of concrete. The cost was somewhat less than that of these walls, but they were about 5 feet less in height. He was glad to see that the foundation of the wall was carried down 6 feet below the bottom of the dock, and he did not apprehend there could be any failure, judging by the section exhibited; yet his impression was that three or four years ago a portion of the wall of the dock had slipped forward.

The Author had given the cost of the whole work at £467,000. Summing up the length of the dock walls as far as he could

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vii., p. 159.

ascertain generally from the plans, it amounted to about 8000 feet: that would represent only £100,000 out of the total cost. He would be glad to know what was the cost of the 300 feet lock, and the cost of the lock gates; also what was the diameter of the pivots. The arrangement by which not only the gate-rollers, but the roller-frames, might be lifted out was an excellent one, because the rollers would wear, and unless the whole apparatus could be got out, no repairs could be effected without a cofferdam; even a diver would be of no use. He had used wooden sills for dock gates years ago, and for dry docks did so still; but for ordinary dock gates and basins he had used granite without any sill, and he found it answer perfectly, granite being permanent, and wood being liable to decay. He was delighted to hear that so large and important a work as this could be fitted with hydraulic apparatus for the comparatively small cost of £19,000. He had never fitted hydraulic apparatus to dock works, having been hitherto deterred by the great cost of it: in this case the sum of £19,000 was well spent.

Looking at the length of ships of the present day, he considered the lock entrance of 300 feet would be found somewhat short. The width was ample, because paddle-wheels were things of the past for sea-going vessels, and a width of 55 feet was ample for a screw-vessel of the largest size. He would ask what thickness of puddle was found necessary for the bottom of the dock, and whether it was effectual in preventing leakage? Also, whether at the entrances of the locks, where vessels coming in worked round the quoins, anything better than brickwork was built into the quoins? He had found in some instances that, either from the rubbing of the sides of the ship, or the working of the screw, the face of the wall was seriously damaged, though built of rubble in hydraulic lime. He had repaired the walls, but he still found they were affected, and it was a question whether large stones ought not to be used instead of brickwork for the entrance quoins.

Captain Calver, R.N., remarked that one portion of this subject often fell within his own observation; and that was the junction of lock entrances with the river stream. He had observed on several occasions that the system was generally to make a rectangular junction, but he believed that in the majority of cases, this arrangement was very objectionable for docking a vessel. He had in his memory a dock where the entrance and exit were extremely hampered; for instead of the engineer inclining the entrance a little up-stream to enable a vessel to be docked easily, the lock entrance was transverse to it; and the consequence was that the

greatest difficulty was experienced in getting vessels into the lock entrance, from their being pressed against the knuckle of the upper wing-wall when the stream was running. It was generally the case in tidal rivers that the flood stream continued for some time after actual high water; and therefore, without going too minutely into details, he thought, as a general principle, it was better to incline the entrance upwards, to recess the river-wall above the lock entrance within that of the wall below it, and also to make the upper wing wall with an easy curve instead of with a sharp knuckle. Respecting the particular lock entrance to which he referred, he did not know who was the engineer of it, but he had perceived in this instance, as well as in several others, that this recessing was desirable, and if it had been suggested to the engineer who projected the lock, it would have saved much trouble in docking ships. The only drawback he was aware of to such a principle was extra silting in the enlarged recess; but when the facility the arrangement would afford for docking was considered, a little increased deposition scarcely weighed as an objection to such a plan.

Mr. Hawkshaw, Past-President, in reply to some of the observations on the Paper, said the reason why allusion had not been made to the supposed cause of the failure of the wall was because it was a matter of litigation, and it was not thought desirable to introduce before the Institution a question which was *sub judice*. Inasmuch, however, as the matter had since been arranged there was no reason now why it should not be mentioned. It was the fact that two portions of the south wall, opposite to the Milwall Dock, were pushed forward soon after that dock was filled with water. The contractor alleged that it would not have happened had the Milwall Dock Company puddled the bottom of their dock. That dock was constructed on a formation very much like that of this dock—sand and gravel,—the gravel being in places large and open. Immediately the Milwall Dock was filled, the water began to find its way into the works. It rose behind the wall, and two pieces of it were pushed forward. The wall itself was strong enough, because it moved forward and maintained the upright position in which it had been built, and the walls were rebuilt of the same section. From the way in which these walls behaved, it was evidently not a question of want of mass. The wall was not overturned. It was a case where the pressure of water behind the wall overcame the resistance of the friction of the base of the wall, and the wall was launched forward like a ship on ways.

The whole work was executed at a schedule of prices, and consequently the accounts were in that form; but it would be easy to get out the cost of any particular portion of the work.

He scarcely knew in what way Captain Calver's observations applied in this case. There was no difficulty in docking a vessel, nor did he see how the entrance could be improved.

As a rule he did not use fenders; and he had constructed large docks, for a large trade, without wooden fenders, and found no necessity for them. He had noticed in places in some old docks where wooden fenders had been applied that they had been mischievous. When fenders were put in they must be fixed to the walls. Vessels struck them, and he had noticed that they did more harm to the wall than good. He was now constructing a dock at Dover, at one end of which the old wall remained protected by wooden fenders, and he should take them all away and stop up the holes they had already made. Well-found ships carried fenders of their own, to prevent their rubbing against walls; and generally shipowners used fenders to protect their own ships.

It would require time to get out the cost per cubic yard of the dock wall; but assuming the dimensions of wall to be 40 feet high and 10 feet thick, which was about the section in this case, the cost of the brickwork and concrete would come out about 13*s.* per cubic yard.

Mr. Giles said he approved of what Mr. Hawkshaw had said with regard to fenders, but his question applied rather to the entrance quoins being protected by larger materials than bricks or small stones.

Mr. Hawkshaw replied that the quoins were of Bramley Fall stone, the sills of granite. He did not consider that a wall should be so weak in texture as to be pulled to pieces by the action of screws. He had never known a case of that kind himself.

Mr. R. Rawlinson, C.B., contended that the culverts shown in the section of the walls were liable to burst. He did not suppose that any failure of these culverts had as yet taken place. He assumed, however, that they were built in the substance of the wall. Now in his experience, in two cases, culverts in dock walls of thirty or forty years' standing had burst, and had rent the walls above the culverts as if gunpowder had been used. Mr. Hartley, to make good one of these failures, adopted cast iron, and subsequently never used other than flat culverts, or cast-iron pipes bedded in the wall. The first case was that of St. George's Dock-Basin, one of the oldest in Liverpool. The basin side cloughs got silted up; the tide had risen 21 feet above the old dock sill,

and at low water the wall was split vertically from top to bottom through the solid masonry. Subsequently a similar accident happened in the old tidal basin on the Bridgewater canal, at Runcorn. When therefore culverts in dock entrance walls were liable to remain full of water, under pressure, they should not be of ordinary construction; it would be better to make them of cast iron, or to put them behind the walls.

Mr. Abernethy remarked that in designing docks, engineers had to take into account the nature of the traffic to be accommodated, the peculiarities of the site, and other circumstances which governed in a great degree the design of the docks and their ultimate cost. He highly approved of the general design of the dock under consideration, as it was admirably adapted for the particular trade of the West Indies. He referred first to the accommodation afforded by the jetties for the special traffic of these docks; they greatly increased the quay accommodation, and for a traffic such as this, which was a general mercantile traffic, that arrangement was an exceedingly convenient one. The same, however, would not apply in the case of docks designed for mineral traffic. For the particular class of vessels using the West India Docks, he thought a lock of 300 feet in length was sufficient, but it must be borne in mind that the length of vessels was gradually increasing. He had constructed of late years locks 350 feet in length, and regretted since he had not made them longer, as he found they were becoming too short for the modern class of vessels, particularly steamers, and he wished he had made them 400 or 450 feet long. The width of the lock, 55 feet, was ample for any purpose.

Reference had been made to the fact, that when the Millwall Dock was completed, and the water admitted into it, a large quantity of water found its way into the excavations for this dock, which Mr. Hawkshaw attributed to the admission of the water into the Millwall Dock. The fact was, during the construction of the Millwall Dock, the whole of the water which percolated through the gravel of the Isle of Dogs was being pumped by the contractors for that dock, and he apprehended Mr. Hawkshaw had the same work to perform that the Millwall Dock Company had in carrying out their excavations, and that the extra quantity of water was not due to the Millwall Dock; because, after the water had been admitted into that dock he observed a small excavation near the end of it, and there he found the water remaining at the normal level of half tide, or considerably below the surface level of the Millwall Dock. No doubt one company pumped all the water

during the progress of their work, and on ceasing pumping it fell to the other company to do the same thing.

Reference was made to the exceedingly moderate cost of the dock wall; but so much depended upon the nature of the site and the materials to be dealt with, that the cost of one dock wall could not be compared with that of another. He had constructed dock walls at much less than the £36 per lineal yard mentioned in this case. He was now constructing a dock wall which cost £39 per lineal yard, whilst he had built walls equally effective on a gravel site, where the lateral pressure on the wall was slight, for £24 per lineal yard. But in the former case he had to deal with a deep alluvial deposit, similar to that in the site of the dock now being constructed at the mouth of the Avon, and there the walls must be of great thickness.

As regarded the accident to the wall, the wall as designed was sufficiently strong for all purposes. He thought the failure arose from want of sufficient drainage. A similar kind of accident occurred at the Birkenhead Docks. The walls were of sufficient thickness to resist, under all circumstances, the pressure behind them, but the water was admitted into the docks and then suddenly withdrawn, and the land behind the walls being charged with water, and no due provision having been made for drainage, the result was the wall moved bodily forward. In building dock walls he treated them during construction as retaining walls, and at intervals of about 100 feet he provided for drainage through the wall, by pipes with dry rubble drains behind. The advantage of that plan he experienced at the Swansea South Dock. In that case the works, for want of means and other circumstances, were suspended for a considerable period, and after the walls had been constructed, the leakage into the dock filled it almost up to the ordinary spring tide level. He afterwards drained off the water gradually, a few inches every day, to continue the works, and succeeded in laying the dock dry without any injury to the walls.

Locks at an angle down-stream were very inconvenient, because of the interference with the working of the dock. A trumpet-mouthed entrance, with a sufficiently long wall down-stream, was all that was necessary for a vessel to pass in and lie alongside the wall. It was inconvenient to enter a dock by a long lock placed at an angle to it. He had always used granite sills, and he thought that timber between the sill face and the lower rib of the gate should be avoided as unnecessary. He had constructed three docks in gravel, the Silloth, and the Swansea North and South

Docks, and in neither case had he found it necessary to resort to puddle lining.

Mr. HAWKSHAW said it should not be overlooked that the basin of this dock was really a lock, and vessels from 300 to 400 feet long could pass in without difficulty, and there could be no difficulty of admitting the longest vessels.

Mr. BRUNLEES remarked that in designing the dock at King's Lynn he had laid out the lock with the entrance pointing up-stream; but the plans were referred on the part of the Corporation of Lynn to Mr. Abernethy, who objected to that direction being given to the entrance, and said it should be placed at right angles to the river, which was done. On the day of the opening of the dock a large steamer took the Prince and Princess of Wales and other eminent personages into the dock, and exactly what was apprehended did happen, the vessel being thrown by the force of the tide flowing up stream athwart the entrance to the lock. He was glad to say, however, that this accident was the first one and the last with respect to that entrance, and no practical inconvenience from that time to this had been felt from it being at right angles to the river. Though many vessels might pass in on the flood, still there were other vessels which would pass in after the tide had ceased to flow; and the best way, in his opinion, was to adopt that which suited the average, and that was a rectangular entrance.

Recently, at Avonmouth an accident had occurred which he would describe. A wall had been built some time and had apparently firmly set, but one night a portion, 80 yards in length, moved forward about 4 feet, without disturbing the batter at which the wall was built; and though some months had elapsed, no further change had taken place; and he supposed there would not now be any further alteration in its position. He believed the cause was this: in building the wall it must have crossed, at the site of the accident, an ancient channel or byewash, in which the deposited layers of material were softer and more slippery than the rest of the foundations, and that the wall had slid forward to its present position. He had not met with anything similar in other parts of the dock foundations, and, from the position of that part of the wall which had moved, he thought the only possible explanation of the movement was the one he offered.

Mr. J. GRANT said that, assuming the dock wall to be 41 feet in height, and of an average thickness of 13 feet, the cost of the combined brickwork and concrete would be about 12*s.* per cubic yard—not a very large price for a construction of brickwork and

concrete probably in about equal proportions. But he thought a wall equal in strength, and still cheaper, might be made of more homogeneous character, viz., concrete, either alone, or with a thin facing of brickwork. He should prefer Portland cement to lime for strength. The 14 inches of brickwork at the back of the wall seemed unnecessary for retaining the concrete, which would form a sufficient face of itself. The cross walls, too, he considered unnecessary. Walls built with pockets, though cheaper than if built of solid brickwork, had this great defect; that the angles of the pockets formed so many weak places liable to crack and separate; and the wall, taken as a whole, was not so strong as if built of one material—stone, brick, or concrete.

Mr. Harcourt, in reply on the discussion, said that the wall had cost as nearly as possible 12*s.* 6*d.* per cubic yard. Though the dock wall formed only one of the heaviest items in the construction of the dock, he had referred to it specially as being the one item in which economy could be attained, by judiciously employing the materials most suitable to the particular circumstances of the case. The other principal items were the east entrance lock, which had cost, inclusive of the excavation, dredging, and cofferdam, about £95,000; the excavation for the dock, passage, basin and warehouse foundations, amounting to 1,600,000 cubic yards, and costing £160,000, owing to the expense of obtaining ground for depositing spoil in the locality; and the rest of the expenditure was made up by the passage; the gates, which cost £4,000 the pair; the jetties costing about £1,100 each; the puddle covering the bottom of the dock and basin, the warehouse foundations up to quay level, the accumulator house, ballasting the quays, the boundary fence, and numerous smaller items, such as pitching and piling at the west entrance lock, buoys and mooring posts. The layer of puddle at the bottom of the dock and basin was 18 inches thick, and he believed that it had fully answered the purpose of preventing leakage into the adjoining low-lying lands.

With reference to the question of the advantage of drainage at the back of the walls, he ought to mention that, when water was found to be rising at the back of the south wall of the dock, holes were bored through the walls to allow it to flow into the dock excavations, and pipes were inserted, at regular intervals, at as low a level as practicable, in the portions of the south walls of the dock and basin subsequently built. The objection to numerous holes through the walls was the difficulty of effectually filling them up again just before letting the water into the dock, which it was most important to accomplish, because, though very useful while

the dock was being constructed, the holes might prove a source of great damage if left open after the dock was filled; for a reverse action would then take place, the water would flow from the dock to the back of the walls, and, if at any time the water was suddenly lowered in the dock, there would be a great head of water at the back of the walls.

As an additional precaution, to prevent any tendency to slide, owing to unusual pressure at the back and the faulty nature of the soil, the foundations of the south wall of the basin, which rested on clay intermixed with layers of sand, were carried 2 feet 6 inches lower down, so that at that place the foundations were 8 feet 6 inches below the dock bottom. The sills were made entirely of granite, and no woodwork was introduced; but the shutting sills of the gates were of greenheart. The steel pivot on which the gate turned was 1 foot in diameter.

It had been suggested that concrete with a facing of brickwork might have been adopted for the walls. Any larger employment of concrete would have cheapened the cost of the walls, but there would doubtless be considerable difficulty, in building a wall in the manner proposed, in bringing up the concrete and keeping it in place whilst being brought up, added to the disadvantage of having two separate walls, one of brickwork and another of concrete.

April 23, 1872.

T. HAWKSLEY, President,
in the Chair.

No. 1,310.—"River Witham Drainage: Pumping Machinery and Works at Lade Bank." By EDWARD WELSH, M. Inst. C.E.

AN account of the recent application of steam power, for the drainage of the fourth district of the river Witham, will, it is hoped, be found to possess interest, both from its magnitude, and from the type of pump adopted. The works were designed by Mr. Hawkshaw, Past-President, Inst. C.E., the consulting Engineer to the River Witham Drainage Commissioners, and were carried out under the immediate superintendence of the Author, as the Resident Engineer for the Commissioners.

The fourth district of the river Witham consists of three subdivisions called the Wildmore, the West, and the East Fens. It has a watershed of about 82,226 acres, of which 62,226 acres are taxable by the Drainage Acts.

Previous to the construction of the works forming the subject of this Paper, about 15,000 acres in the West Fen, and 25,000 acres in the East Fen, were in all winters very imperfectly drained; and in winters of more than ordinary rainfalls about one-half of those areas was submerged, sometimes, as in the winter of 1866-67, for several consecutive weeks. In this condition the land remained from about the year 1800 to 1860, when portable engines, having come into general use, for threshing and other forms of farm-labour, were also gradually applied, on some of the larger farms, to the additional duty of driving pumps of the well-known scoop-wheel type. Of these, as many as ten, having an aggregate power of from sixty to eighty horses, were in operation in the East Fen prior to the year last mentioned. The disadvantages of individual action, however, soon became apparent, both to those by whom it was being made, as well as by the smaller and less enterprising occupiers. To the former it was speedily revealed that the operation, to be effective, must drain, not only the occupation to which it was applied, but, in a great degree, the adjoining occupations also. To those who, on the other hand, did not employ steam-pumps, it appeared that they

were injured by those who did, in consequence of the greater elevation given, as they believed, to the water in the main drains.

The Commissioners thereupon requested their Consulting Engineer to advise as to the best scheme for the improvement generally of the whole six districts of the commission, and also as to the best scheme of improvement for the fourth district alone, if it should become necessary for the latter to proceed without the co-operation of the other districts. In June, 1861, Mr. Hawkshaw reported as to the efficiency and economy which the application of steam would afford to the drainage of the fourth district. He added, however, that, looking to the future of the whole six districts, such an expenditure of the funds of the fourth district would be regretted.

The Commissioners renewed their efforts to obtain a general scheme, but being unsuccessful in this, in the year 1866, Mr. Hawkshaw received instructions to take the necessary proceedings for enabling application to be made in the next session of Parliament for powers to carry out the scheme of steam drainage for the fourth district alone. That application having been successful, the works delineated Plates 22 and 23 were constructed.

The works comprise—

(1st). A sluice or dam, having in it three water-ways, each 12 feet wide, and of the same height as the dam, closed by ordinary swing-gates in pairs. Of these, the central water-way is also a navigation lock, having two pairs of gates.

(2nd). Two pump-wells, each 12 feet wide, also closed by ordinary swing-gates in pairs, and over which is constructed the engine-house, and,

(3rd). The boiler and coal-house adjoining, which is the chimney.

In each pump-well there is a double suction Appold centrifugal pump, having a propeller, or fan, 7 feet in diameter and 2 feet 2 inches in width, carried upon an upright shaft, which passes through a stuffing-box bearing in the top suction pipe, and hangs by a union suspension bearing in the engine frame. This upright shaft carries a bevil pinion, in gear with, and driven by, a mortice bevil wheel on the union shaft of a pair of steam-engines. The whole of the machinery of each pump, with its pair of engines complete, is self-contained on one and the same bed plate, and works independently. Each machine is a duplicate of the other.

The engines are high-pressure, condensing, vertical, and direct-acting, with rocking-beam parallel-motion. The cylinders are

30 inches in diameter, with a length of stroke of 30 inches, and have double steam ports. The slide and expansion valves have independent motions, and are also fitted with equilibrium cylinders, &c. The expansion motions have tangent screw adjustments, by which the rate is at all times easily varied. The pistons have double metallic rings, with flat steel springs and steel rods. The air-pump cylinders are $23\frac{1}{2}$ inches in diameter, with a length of stroke of 15 inches. The two pairs of engines are supplied with steam by six cylindrical boilers, each 23 feet in length and $6\frac{1}{2}$ feet in diameter, with two inside furnaces and flues; the furnaces are $2\frac{1}{2}$ feet in diameter and 5 feet in length. The pressure of steam in the boilers is 45 lbs. on the square inch. The engines are worked expansively, the steam being cut off in the cylinders at one-fourth of the stroke of the pistons, and the engines make 36 revolutions per minute.

The excavations, buildings, and machinery were let in one contract for a sum of £17,000, to Messrs. Eastons, Amos, and Anderson, and by them completed in the most satisfactory manner.

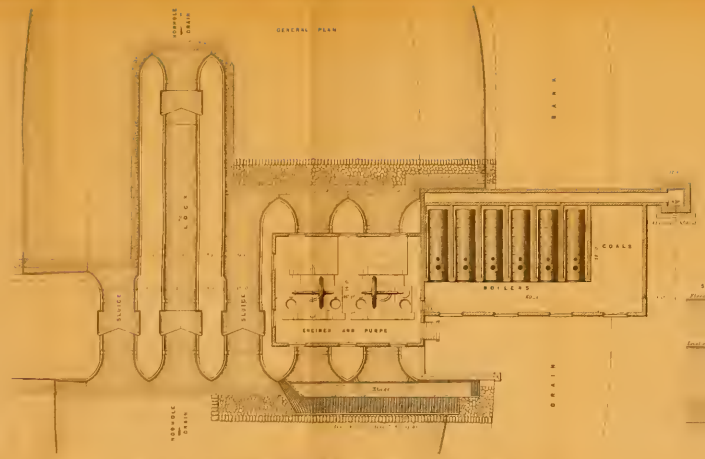
The entire drainage of 35,000 acres was now performed by the works described, all the pumping engines previously in use in the fourth district having ceased working. In the winter following their completion, there was an excessive rainfall in the district, and the new machinery was severely tested. Within thirty-six hours, on the 7th and 8th of December, 1870, there was a fall of rain of 0·94 of an inch, and the total rainfall of that month was 50 per cent. in excess of any winter month in the previous forty years. The Author reported this at a meeting of the Commissioners, on the 9th of January, 1871; and further, that whereas in January, 1867, with a rainfall of 3·32 inches, an area computed at from 10,000 to 12,000 acres was placed under water for several weeks, the new machinery, in the month of December, 1870, with a rainfall of 5·28 inches, had kept the whole district perfectly clear. But one opinion appeared to prevail in the neighbourhood as to the effect of the works, that, in the winter referred to, the saving of property had been greater in value than the whole cost of their construction, and that they have since given complete satisfaction.

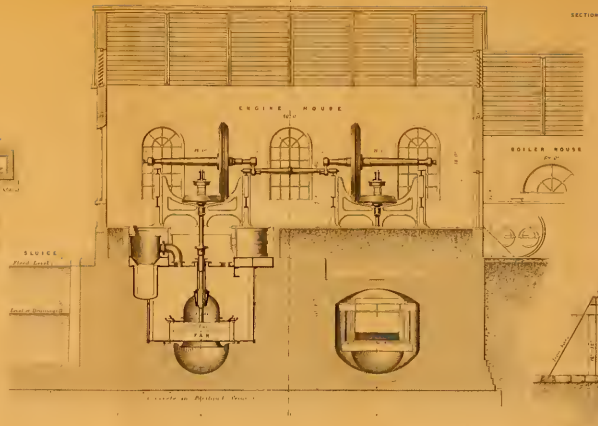
The communication is accompanied by a series of diagrams, from which Plates 22 and 23 have been compiled.

RIVER WITHAM DRAINAGE.

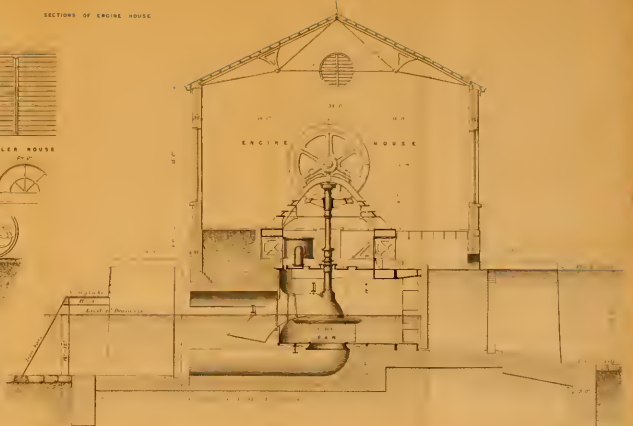
ASC DISTRICT.

WORKS AT HOBHOLE DRAIN NEAR LADE BANK BRIDGE





SECTIONS OF ENGINE HOUSE



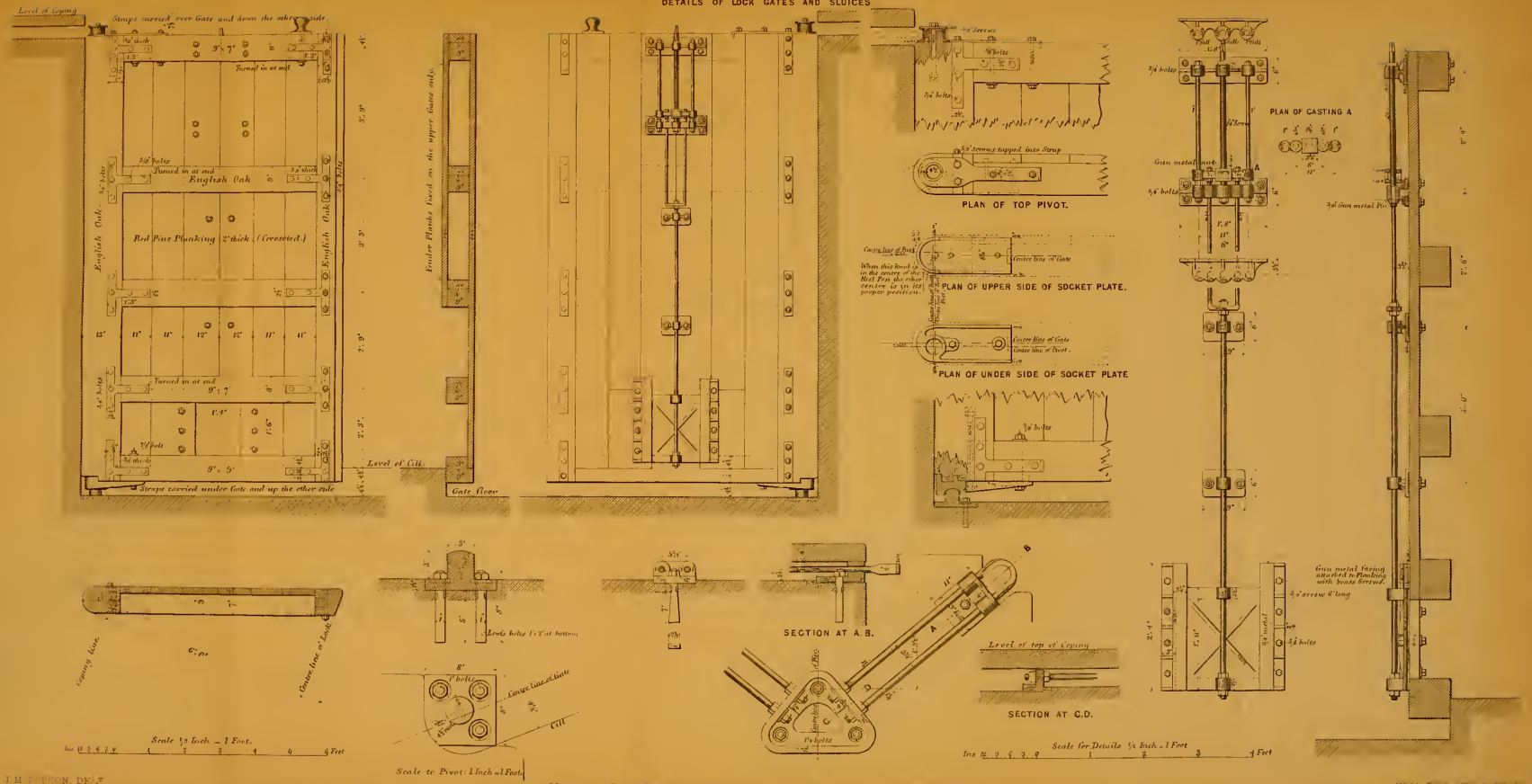
RIVER WITHAM DRAINAGE.

PLATE 23

472 DISTRICT.

WORKS AT HOBHOLE DRAIN NEAR LADE BANK BRIDGE.

DETAILS OF LOCK GATES AND SLUICES


Level of Coping
Straps carried over Gate and down the other side
English Oak
Red Pine Planking 2" thick (Creosoted)
Level of Cill
Straps carried under Gate and up the other side
Gate Floor
PLAN OF TOP PIVOT.
PLAN OF UPPER SIDE OF SOCKET PLATE.
PLAN OF UNDER SIDE OF SOCKET PLATE
PLAN OF CASTING A
Gun metal Pivot
Gun metal Facing attached to Planking with brass Screws
SECTION AT A.B.
SECTION AT C.D.
Level of top of Coping
Scale 1/2 Inch = 1 Foot.
Scale to Pivot: 1 Inch = 1 Foot.
Scale for Details 1/2 Inch = 1 Foot

J. M. T. TYSON, DEL.

KELL. BROS. LITH. LONDON

APPENDIX.

STATISTICS OF WORK.

	Year ending 31st March, 1871.	1872.
Average revolutions made by engines per minute	36·02	38·2
Average lift in inches	44·77	45
Sum of hours worked by both pumps	794·25	980·5
Weight of water discharged in tons	13,564,190	18,296,130
Coals consumed during working hours ,,	328	397·25
Engine oil used gals.	25·75	20·25
Tallow used lbs.	181	135
Waste used ,,	135	85
Wages paid, viz.—	£ s.	£. s.
First and second drivers, yearly	158 12	158 12
Boy, yearly	15 12	18 4
Firemen, 2,085½ hours, at 3½*d.* per hour	30 8	29 13
,, 2,033 ,, ,,		

[Mr. WELSH

Mr. Welsh observed that the total expense of pumping, for the year ending the 31st of March, 1872, was £573; for the year preceding it was £490, or from 3½*d.* to 4*d.* per acre drained, for working expenses alone, exclusive of interest on the capital. The cost of the works was about 10*s.* per acre, which, taken at 4¼ per cent., gave about 5*d.* per acre. The rate levied was 6*d.* per acre, which was the utmost amount the Commissioners had power to raise under the Act of Parliament. The taxable area, and the area upon which the pumps operated, were nearly in the proportion of 2 to 1.

Mr. Hemans, Vice-President, said the total annual expense, including interest on capital, appeared to be about £1,271, and comparing that with the acreage, it was under 4*d.* per acre, the most moderate cost he had ever known for such a work.

Mr. Woods asked whether a comparison had been made between the cost of pumping with the centrifugal pump and with the scoop-wheel. The pumping machinery in use at the Amsterdam Sea Canal works was similar in construction to that described in the Paper, and worked with the same class of pumps and engines, applied to the drainage of the Y estuary of Amsterdam. He found that the centrifugal pump was almost a new application with the Dutch engineers, and that the scoop-wheel and Archimedean screw were still in favour in Holland. Although the Dutch engineers were ready to admit the inferiority of the latter to the centrifugal pump in some respects, it was questioned whether the adoption of centrifugal pumps would not be attended by increased cost in pumping.

Mr. Beardmore said the advantage of centrifugal pumps, which included all classes of turbines, was the concentration of power afforded by the velocity with which water could be forced through them. It was doubtful whether they were economical when velocity was pushed too far; but this became a secondary object when the duty to be performed was at intervals only, such as pumping out the water from a dry dock, or keeping down a temporary inundation; for in these cases a smaller and more economical machine could be attached when the duty was small.

The scoop-wheel when of large size was expensive in construction, difficult to drive with heavy tail-water, and when land was liable to be reduced in level, after a few years' pumping, the turbine could be arranged for future permanent lowering with much greater facility. Moreover, it was disadvantageous to drive a

scoop-wheel fast, as indeed it was to drive a turbine slow; and thus, now that steam of high pressure and engines capable of great speed were used, there was a power, on an emergency, of throwing a large volume of water with comparatively small and economical machinery. The drainage of Haarlem Meer was executed by the ordinary pump, and was an extremely heavy work for about two years, when the water had to be first exhausted from the district. If this preliminary duty had been done by turbines and temporary engines, the saving would have been considerable, and the establishment of permanent engine-houses, with pumps for the ordinary drainage of the district, could have been much reduced. In the case of the Witham drainage, the application of Cornish engines and ordinary lift pumps, working at a moderate speed, doubtless afforded the most permanent economy.

An excellent example of the principle involved was afforded below Hertford, where by Act of Parliament, in 1855, the New River Company were compelled to keep up the supply to a water-mill of 6 feet fall, a volume of 5,000 cubic feet per minute, *i. e.*, if the natural stream gave only 1,200 cubic feet, 3,800 additional cubic feet had to be thrown up by engines from the tail-water.

In that case, two centrifugal pumps, capable of throwing 1,500 and 2,500 cubic feet of water per minute respectively, were driven by an ordinary single cylinder engine, with a fly-wheel and band on its edge. The machinery, which had been erected by Messrs. Hunter and English, was simple and economical in first cost, and in the fourteen years of its existence had been only used about five years, more or less, viz., from July to November in each year. He mentioned this case as the steam-engine had rarely been applied to supplement water-mill power on such a large scale, and under the circumstances so economically. The mill was eventually purchased by the Water Company, and the pumps had been recently removed.

He might observe incidentally that centrifugal pumps, when most conveniently placed for being driven from the engine, were apt to lose water when stopped. This fault caused recurring detentions, and there was no real cure but to apply a charging cistern of water above the pump, with a pipe and stop-cock for turning water on, so as to keep the pump full until it had commenced its proper duty.

Mr. Redman remarked that the interest of the Paper would have been enhanced by a description of the topography and of the

general bearing of these works upon the river Witham. On a former occasion the effect of the sluices carried out by Smeaton in the river was referred to; and in this Paper allusion had been made to the effect of draining a confined area into one outfall, and of raising the level of the common drainage water. The object of modern engineering works in the Fens had been to bring the general drainage of the district into coincidence with the natural conditions of the drainage externally; in other words, to render the main effluent water more sympathetic with the action of the tides outside. Many works, unexceptional in themselves, designed with great care and judgment, and fulfilling all the requirements for which they were intended, had often been antagonistic to other interests in the district. The most comprehensive drainage schemes of late years had been to lower the outfall towards the sea as much as possible, and to deepen and widen the main drain common to the surrounding districts. That was the object of the large works last carried out by the Commissioners of the Bedford Level—the Middle Level works—by which the outfall had been lowered several feet, and the main drain carrying it up country, had been widened and deepened. The effect of those works was to drain the Whittlesea Mere, and to lower all the outfalls into the main drain. The early pumping-engines, driven by windmills, raised the water from the Fens into an aqueduct, very often above the level of the circumjacent Fens, and a large amount of that water percolated back again through the banks. But the Middle Level works deepened the main drains so materially, that the windmills were gradually disused, and eventually done away with. They were in some few instances succeeded by steam-engines, fixed at lower levels. The first application of the Appold pump in the Fens was for the drainage of that part of Whittlesea Mere which was below the general level of the drain.

Mr. SIEMENS said there seemed to be a consumption of 12 lbs. of fuel per H.P. of actual water lifted; but he thought it would be wrong to blame the pump alone for that result, for although the Author had not given the details of construction of the engine, yet sufficient information was conveyed as to its character. to stamp it as one of a very commonplace description. It appeared that the steam was cut off only at one-fourth of the stroke of the piston, and he supposed no particular care was taken to prevent condensation of steam by jacketing. Considering that a condenser was applied, the consumption of fuel was much larger, however, than it should be; and even though the pump gave a duty of

50 per cent., still the consumption ought to be something like ⅔rds what it was stated to be, or, say, 8 lbs. per actual H.P. per hour.

Mr. T. R. Crampton believed that a pump of the description referred to would not yield more than 50 per cent. of duty, and that left 5½ lbs. of coal per H.P., and he was sure an engine of the kind used, having no proper steam jackets, could not be worked with less than 5½ lbs. per H.P. per hour.

Mr. Welsh, in reply upon the discussion, observed that the object of the Paper was simply and solely to elucidate the application of centrifugal pumps to the drainage of about 35,000 acres of land. Into the relative question of drainage by gravitation, and improvements of outfalls, as compared with the application of steam, he had no desire to enter on that occasion.

With regard to the observations as to the statistics of the working of the engines and machinery, he might remark that the figures were obtained when they were in an almost unfinished state, while in fact everything was in a crude, and untried and unproved condition. There was no time to adjust a valve or a balance. The engines had to run night and day for three weeks with grit in the bearings, with heated bearings, and with everything else but drowned land. One condition they were determined to adhere to, viz., that no one should have reason to complain that his land was not sufficiently drained; and, as stated in the Paper, he had the satisfaction of hearing, ten days ago, at a meeting of the Commissioners of the district, that during the last three weeks these works had effected a saving of property equal to the whole of the outlay, so that it was not a question of 6*d.* or 4*d.* an acre.

The number of tons of water given in the statistics was a matter of calculation, and not the result of absolute measurement or fact. It was obtained from diagrams of the performances of the engine, furnished by Mr. Anderson, one of the firm by whom the engine was made. When the calculations were made he took the opportunity of testing them by means of current measurements, and he found the results came very close indeed to the theoretical quantity given by the diagrams. He believed it was admitted that the performances of the scoop-wheel and those of the centrifugal pump were pretty much upon a level for the amount of work done. The great recommendation of the centrifugal pump over the scoop-wheel was the economy in the first outlay. It was within his own knowledge, that in three districts of the Witham

which were drained by scoop-wheels, the cost of the engines and constructions, the engines varying from 30 to 40 H.P., was very close upon £1 per acre, while the outlay on the engines and works in the case under consideration was precisely 10*s.* per acre.

No. 1,336.—"On the Construction of Heavy Artillery, with reference to Economy of the Mechanical Forces engaged."[1] By Bashley Britten.

Just twelve years ago a Paper was read at this Institution "On the Construction of Artillery,"[2] and so great was the interest felt in the subject, that it gave rise to a discussion which occupied six meetings. The same topic is again to be submitted for consideration, but from a different point of view. Formerly the question resolved itself into how to make the strongest possible cylinders to withstand internal pressure. A cannon was apparently assumed to be such a simple form of engine, that perfection depended merely on its ability to discharge great quantities of gunpowder without flying to pieces. Obviously it is possible to make a gun which will not burst, and yet it may be but a clumsy contrivance; nothing better, in fact, than a mass of tenacious metal with a hole in it. There exist many examples of such guns, both of ancient and modern construction. A good gun, however, must be something more than merely a strong tube. It is really a scientific instrument, which can only be designed correctly after careful study of many complicated and subtle considerations, as, for instance, how the motive force to be obtained from the elastic pressure of fired gunpowder, may be so controlled and directed, as to yield the utmost useful effect, with the smallest waste of means. It was not possible to treat the subject in this manner when formerly discussed at this Institution, for there were then scarcely any data for practical men to reason upon. Nothing definite was known, either as to what force gunpowder exerted, or how it behaved in exploding. Artillery was made without any correct knowledge of what work had to be provided for; and it would not be wrong

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[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings, Inst. C.E., vol. xix., pp. 283-460.

to say that, notwithstanding all which of late years has been accomplished, no large piece of ordnance has ever yet been made in this country on higher considerations than mere empirical deductions from experience, or, in other words, by guess-work. The time, however, has come when this important matter may be dealt with more satisfactorily. Quite recently facts have been determined, that enable the principles to be considered on which success depends; and henceforth the construction of ordnance may be regarded as a branch of scientific Engineering, in which means can be adapted to ends with as much certainty as in making a steam-engine or any other machine. It must no longer be regarded as a mere official question, and continue to be monopolised by one class of professional men. It belongs to general science, and is at least as likely to be investigated with wisdom by the Civil Engineer, whose whole thoughts are devoted to turning the forces of nature to man's account, as by the soldier or the sailor.

English cannon powder has always been noted for the purity of its ingredients, and for the care bestowed on its manufacture. British artillerymen have most admired its great strength. The strictest care was taken to insure this quality, which was determined by firing a heavy ball out of a mortar of considerable calibre, but only a few inches long. If a certain charge propelled the ball to a certain distance, the powder was considered to be the proper standard. But this test did not really show the strength of the powder; it simply proved its violence. This distinction has only lately been recognised. If the best powder now made were tried in this way, it would appear to be weak and unfit for service. Still it is as strong as the other; it will do as much, and even more work, but it requires more time to do it in.

When rifled cannon began to be used, and heavy elongated projectiles took the place of the old spherical shot and shell, foreign artillerists quickly perceived and appreciated the change of conditions thus imposed on the charge of powder in the guns, and they set to work to adapt the qualities of their powder to these altered conditions. But in England this was neglected, and this neglect has cost the nation millions of money, and years of wasted labour. Attention was principally directed towards strong guns. It was found that guns of wrought metal might be made so strong that they could not burst, and, looking only on the surface of the question, the idea of imitating what was called the foreign weak powder was despised. Years passed over, and this course was pursued. The English "poudre brutale" became the subject

of remark in every arsenal but that of Great Britain. The new English guns were so strong, that none of them ever burst—what more could be desired? There must be nothing in the service but the strongest guns and the strongest powder. The tens of thousands of existing cast-iron and bronze guns, with all their vast stores of ammunition, were to be cast aside as worthless; all plans for improving them were discouraged and condemned, in spite of extensive and perfectly successful trials. A committee of officers reported that, whatever sacrifice of national property might be involved, and whatever it might cost to replace the existing guns with new ones far more expensive, it must be done, and the public had to accept their decision, without option and without inquiry. Two millions and a half of money were spent in four years on the Armstrong breechloaders.[1] Nine hundred and sixty of the 100-pounders were made at a cost of about £700 each, exclusive of the carriages; but the Navy, after trial, refused to use them, and they were condemned. The present muzzle-loaders were then commenced. The system of rifling and the nature of the projectile were copied from the "canon rayé" of France; and, fixing on a general design, in regard to the weight and proportions of the gun, and the charges to be employed, the result was called the "Woolwich system." The Woolwich guns in all preliminary trials succeeded admirably, and once more the course seemed clear. From weapons of 7 tons the advance was rapid to 9, 12, 18, and 25 tons, and finally to 35-ton guns, all of the finest fibrous iron that money could procure. In every respect but one these weapons appeared to be perfect. As regards precision, range, penetration, every quality then looked for, there was nothing in the world to surpass them, even if they could be equalled. When, however, they came to be tested for endurance, it was found that from 500 to 600 rounds was the limit of work to be calculated upon from each without extensive repairs.[2] Owing

[1] The Select Committee "On Ordnance" reported to the House of Commons, on the 23 July, 1863, that a total of £2,539,547 17*s.* 8*d.* had been spent on Armstrong guns and projectiles. (Parl. Pap. 487. Ordnance, 23 July, 1863.)

[2] Five of the 9-inch muzzle-loading Woolwich rifled guns were tested for endurance. Of three of these, after 500 rounds with full service charges, one was reported to be "serviceable," one "repairable," and one "unserviceable." Of the other two, after 600 rounds, viz., 400 rounds with reduced charges of 30 lbs., and 200 rounds with the full service charge of 43 lbs., one was reported to be "serviceable," the other "repairable."—(Parliamentary Return, "Rifled Guns," 10 August, 1869, page 10.) One of the 7-inch muzzle-loading Woolwich rifled guns, in firing 637 rounds, only 85 of which were with the full service charge of 43 lbs., had to be revented twice, and "turned bottom part up, the old vent

to the resistance of the very long shot to the enormous charges adopted, the rush of the heated gases, in a state of extreme tension through the windage space round the projectile at starting, rendered the guns unserviceable in a comparatively short time, by 'scoring' or 'guttering' the iron or steel surface of the bore. An anxious question then arose, which formed the subject of a voluminous report to the War Office, where it is preserved as an official secret. The guns could only be relined in such a factory as that at Woolwich. If liable to so rapid a deterioration, were these weapons after all such as the country could rely upon? Then, and not till then, the aid of science was called in, and it was found that the foreigner was right in his opinion of the strong English powder.

In May, 1869, the Woolwich Committee on Gunpowder and Explosive Substances was appointed. The specific instructions from the War Office, contained in a letter from the Director-General of Ordnance, dated 8th May, 1869, directed that body to "an early determination of the description of gunpowder whose employment in large charges is attended with the least risk of over-straining the guns." The Committee were directed "to make use in this inquiry of any foreign gunpowders," "as well as of every service variety of gunpowder;" and from their Preliminary Report,[1] it appears that among the principal powders subjected to comparative experiment were samples of the descriptions for several years previously adopted in the services of Russia, Prussia, Belgium, Spain, France, and America. All these States were named, distinctly showing how general was the knowledge upon this important point, which had been so strangely neglected in this country. The report of this Committee contains a description, with drawings, of the exquisite instruments which were devised for the purpose of the inquiry,—consisting mainly of improvements on other instruments of a similar character that had long been used in America and elsewhere—and the facts observed by the Committee were graphically represented in several diagrams, showing by curves and ordinates—

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blocked up, and a new one bored;" and then returned to Gun Wharf to be revented a third time.—(Captain Hood's Report in the same Parliamentary Return.)

[1] *Vide* Preliminary Report of the Committee on Explosives. With plates. February, 1870. Printed at the War Office, 1870.

1. The amount of pressure, in tons to the square inch, exerted over every part of the interior of one of the 8-inch guns, when fired with different kinds of gunpowder.
2. The time of the shot's motion within the gun, measured with perfect accuracy, by the severance of electric wires, introduced by means of numerous plugs screwed into the gun from the outside, at various intervals throughout its length.
3. The velocity acquired by the shot as it was being accelerated, from the instant of starting to that of leaving the muzzle.

Here, at last, some of the elements on which the art of gun construction depends were resolved. It is to be regretted that the scientific artilleryman had not at an earlier period furnished the constructive Engineer with such data. In the preceding twelve or fourteen years five or six millions of money had been spent on ordnance; and, all plans for the future having been settled, the inquiry was set on foot as to what the conditions were that the guns had to fulfil.

It is not necessary to describe the instruments which were employed by the Committee, as they are probably well known. It is sufficient to point out that they were of two kinds, both used at the same time, and each affording independent tests, thus serving to explain and confirm what was discovered by each. The pressure gauges indicated, by a mechanical test, the amount of force at work; the chronoscope, by measuring the time of the shot's motion, accounted for the effects of the pressure upon it. Without the chronoscope, the pressure gauges revealed apparent anomalies, which cast distrust upon them. They showed that the powder which exerted the most force imparted less of it to the projectile than other powder far less active; but why this happened was soon made clear by the lightning records of the chronoscope. This will be seen by attentive consideration of Table I. This Table has been prepared by the Author from the figures in the Report of the Committee, and shows the different effects produced by two kinds of powder. The "R.L.G." is the common powder of the English service, and the "Pebble" is that improved kind which has recently been adopted for the Woolwich guns. Pebble powder is denser than the other, and is in larger particles, so as to burn more slowly; but there is little or no difference in the composition of the two kinds.

TABLE I.

COMPILED from the "PRELIMINARY REPORT of the COMMITTEE on EXPLOSIVES."

Gun used: 126 inches long, 8 inches bore.

Shot: cylindrical, 15 inches long, 7·995 inches diameter, 180 lbs. weight. Charges, 30 lbs. of R.L.G. and 35 lbs. of Pebble.

Maximum Pressure, ascertained by pressure gauges placed in the powder chamber . { R.L.G. Powder 29·8 tons per in. / Pebble ,, 15·4 ,, ,,

Distance moved through by the Shot in the Gun.	Time recorded by Chronoscope.		Velocity calculated.		Pressure calculated.		Vis Viva of Projectile.	
	R.L.G. Powder.	Pebble Powder.	R.L.G.	Pebble.	R.L.G.	Pebble.	R.L.G.	Pebble.
	Second.	Second.	Feet per second.	Feet per second.	Tons per sq. inch.	Tons per sq. inch	Foot-Tons.	Foot-Tons.
¼-inch	.. ..	.. ..	..	..	29	1·1	.. ..	.. ..
1 ,,	.. ..	.. ..	360	80	18	6·2	42	8
2 inches	·00049	·0026	..	..	16·7	10·5	.. ..	.. ..
3 ,,	.. ..	.. ..	510	260	15·9	13·4	145	85
4 ,,	·0008	·0033	..	..	14·8	14·7	.. ..	.. ..
6 ,,	.. ..	.. ..	630	460	13·9	15·4	496	264
8 ,,	·0013	·0040	..	..	12·1	15	.. ..	.. ..
10 ,,	.. ..	.. ..	780	650	11·8	14·2	.. ..	.. ..
12 ,,	·0017	·0046	..	..	10·9	13·2	.. ..	.. ..
14 ,,	.. ..	.. ..	840	760	10	12·1	.. ..	.. ..
16 ,,	·0022	·0050	..	..	9·3	11·4	.. ..	.. ..
20 ,,	.. ..	.. ..	950	900	8·2	10·1	.. ..	.. ..
28 ,,	.. ..	.. ..	1,060	1,025	6·5	8·3	.. ..	.. ..
32 ,,	·0035	·0064	..	..	5·8	7·6	.. ..	.. ..
40 ,,	.. ..	.. ..	1,160	1,170	4·7	6·2	1,682	1,711
48 ,,	·0046	·0075	..	..	3·9	5	.. ..	.. ..
56 ,,	.. ..	.. ..	1,240	1,290	3·1	3·8	.. ..	.. ..
64 ,,	·0057	·0086	..	..	2·3	2·9	.. ..	.. ..
76 ,,	.. ..	.. ..	1,305	1,350	1·7	1·9	.. ..	.. ..
88 ,,	·0073	·0101	1,320	1,380	·8	1·0	2,177	2,380

This Table shows an extraordinary difference in the maximum pressure on the gun produced by the two kinds of powder. It likewise indicates exactly on what parts of the gun the various degrees of pressure are exerted; and an insight is obtained into the laws which govern the amount of force remaining, as the gases expand and the heat is dissipated.

In acting on the shot it is seen how differently the velocity is imparted by the two explosives. The whole distance moved through was the same in both cases, but one kind of powder took about 25 per cent. more time to expel the projectile from the gun than the other did. The R.L.G. appears to have burned so fiercely, that probably the whole charge was converted into gas before the shot had moved any appreciable distance. The pressure from it accumulated in the chamber so fast, and then acted with

such intensity, that when the shot did move it started off with a spring, the shot showing in the first inch of its course an attained velocity of 360 feet per second. In doing this the pressure on gun and shot had come down from its maximum of nearly 30 tons to 18 tons per square inch. The pebble powder, however, could not disengage its gas so rapidly. As the gas formed the shot began to move slowly. In the first inch passed over it had only acquired a velocity of 80 feet, instead of 360 feet per second; the pressure was increasing, but at this point was only 6¼ tons per square inch. When a distance of 2 inches had been moved through, the pressure from the R.L.G. had come down to 16·7 tons, while the pebble had got up to 10·5 tons; and it will be observed, from the time recorded, about which there can be no doubt, that the R.L.G. had jerked the shot this 2 inches in just about half the interval that the pebble powder had pushed it. The charge of R.L.G. had exerted its greatest effort on the gun before the shot was under weigh. The charge of pebble powder, on the contrary, went on gathering strength as the shot was advancing for about 6 inches, and here it arrived at its maximum pressure of 15·4 tons. Owing to this increased space for expansion it could not get higher; and from this point it began to descend, but it will be seen that it continued to urge the shot with greater vigour than the other. The result, as might be expected, was that the race was won by the steady persistent force. In a course of 40 inches, the pebble powder was driving the shot with greater speed than its violent rival, and the projectiles finally left the gun with a velocity of 1,380 feet per second in one case, and of 1,320 feet in the other. Here another fact presents itself which requires to be particularly noted: as the projectile passed out of the muzzle the pebble powder was still acting upon it with a force of 2,240 lbs. per inch, or nearly the pressure of 150 atmospheres. All this was wasted in the air. The gun was of the ordinary dimensions, and the charge that adopted for the service.

The instruments by which these figures were determined have been long enough in use to enable those who employ them to judge whether they can be relied upon. Nothing has yet been disclosed to cast a doubt on their general accuracy. On the contrary, experience tends to show, by the uniformity of the results, that they afford the most perfect comparison that can be desired.[1] Whether the actual amount of pressure is or is not

[1] No discrepancies are ever found in the numerous powder trials made in the 8-inch smooth-bored test gun.

expressed in absolutely correct terms, of so many tons per inch, is of little moment, so long as a fair measure of the relative quantities is obtained. Most probably the terms are very nearly correct; at all events the authorities are satisfied with the observations, and continue to rely upon them, so that it is safe to generalise on what these valuable instruments have revealed.

Besides the 8-inch gun, the Committee have had a 10-inch rifled gun, and a much smaller one, prepared in a similar manner for the chronoscope; and they have also devised means of measuring the pressures within other guns, by inserting the gauge either in the vent or in the projectile itself. Some of the more important measurements thus obtained will be found in the Table II., in which the same two kinds of powder are further compared as to their effects.

TABLE II.

PRESSURE on GUNS, produced by the new PEBBLE POWDER, compared with that from the COMMON SERVICE R.L.G. POWDER.—(From various Official Reports.)

GUNS.	Pebble.			R.L.G.		
	Charge.	Pressure.	Velocity.	Charge.	Pressure.	Velocity.
	Lbs.	Tons per sq. inch.	Feet per second.	Lbs.	Tons per sq. inch.	Feet per second.
8-Inch (not Rifled). Shot, 180 lbs.	35	15·4	1,374	30	29·8	1,324
10-Inch (ditto). Shot, 400 lbs.	70	21	1,364	60	51	1,318
10-Inch (Rifled). Shot, 400 lbs.	70	19·1	1,351	60	43·2	1,292
35 Ton Gun, 11½-Inch Bore. Shot, 700 lbs.	75	17	1,163			
	100	25·4	1,237			
	110	31·8	1,303			
	120	46·3	1,364			
	130	63·7	1,348			
35-Ton Gun, 12-Inch Bore. Shot, 700 lbs.	110	18	1,272			
	115	20	1,293			
	120	27	1,341			

These figures point to one inevitable conclusion. The Woolwich guns were all designed for an entirely different kind of work to that which for the future they will have to perform. The 8-inch guns, for instance, were made strong enough to sustain in service a maximum pressure of from 25 to 30 tons, but henceforth, with the new powder, they will never be subjected to more than about one-half this pressure.[1] The 10-inch guns were con-

[1] In March, 1872, Messrs. Hall and Co. sent several samples of improved pebble powder for trial at Woolwich, one of which produced in the 8-inch gun a velocity

structed for what turned out to be a pressure of from 40 to 50 tons per inch, but, with the largest charges that can be used with the slightest advantage, they will never be taxed beyond 19 or 20 tons. All the wrought-iron guns were made for the violent R.L.G. powder. They have been proved with it by extra charges, so that they possess proper margin of strength beyond what they would have to endure in service with this old powder, and with this pressure they were pronounced to be, in regard to their structural strength, almost indestructible. The interior might suffer from local wear, and require renewals, but this did not affect the whole fabric. It is questionable whether they are in any degree better for having such a superabundance of strength. One thing however is quite clear: every increment of strength represents so much hard cash expended in labour and material, quantity or quality, to produce it. If, then, there is more than can be rendered available, just so much public money has been sunk in wholly unproductive work. It has been the custom to boast of their being infinitely superior to the ordnance of other nations because they are so much stronger; but the foreigner simply says that his guns are strong enough, and would be no better for being ten times stronger. It is certain if the new guns were only one-half as strong as they are, they would be as perfect, in respect to the new conditions now applied, as when declared to be perfect for the duties they were originally designed for.

It might be supposed that, when these facts became known about two years ago, some alterations would have been adopted for reducing the excessive cost of the weapons. But the idea of making the slightest change does not seem to be entertained. The models and patterns settled and sealed eight or ten years ago remain as the models for to-day and to-morrow; the designs are fixed, and, right or wrong, they are to be persevered with.

It is proposed then to examine the principles which are represented in these designs. There appear to be two chief points to be considered. The first relates to the material, whether that which is employed is in all respects the most proper. The second question is, whether the power, as it is employed, is used to the best advantage.

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of 1,457 feet, with a pressure of only 16 tons per inch; and another sample gave 1,411 feet, with only 13 tons pressure. The charge was 35 lbs. of powder, and a 180 lb. shot in each case.

I. As to the materials used.

TABLE III.

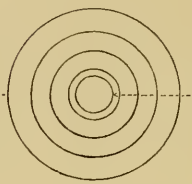
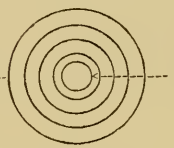
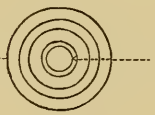
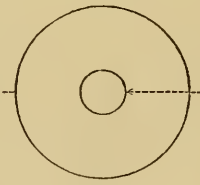
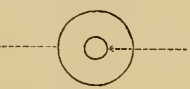
Guns.	Transverse Section at seat of Cartridge.	Thickness of Metal.	Charge.	
			Shot.	Powder.
		Inches.	Lbs.	Lbs.
1. 35-Ton 12-Inch Rifle, Wrought Iron. Bore 162·5 inches . . .		22	700	[1] 130 120 [2] 120 110
2. 18-Ton 10-Inch Rifle, Wrought Iron. Bore 145 inches. . . .		17·5	400	70 60
3. 9-Ton 8-Inch Rifle, Wrought Iron. Bore 118 inches. . . .		13·5	180	35 30
4. 20-Inch American Cast Iron, smooth bore. Bore 210 inches . .		22	1,080	200
5. 68-Pounder, 95 Cwt., Cast Iron, smooth bore. Bore 113 inches		9·2	68	28 16
6. 32-Pounder, 56 Cwt., CastIron, Rifled, Britten's. Bore 108 ins.		6·4	32 50	21·5 10 5

Table III. has been prepared to enable comparisons to be made in respect to various details in several kinds of ordnance of different types. The transverse sections through the seat of the charge are all to the same scale, and show the thickness of metal provided

[1] Bore 11½ inches diameter. [2] Bore 12 inches diameter (bored out).

TABLE III.

Section of Bore, showing Space occupied by Powder.	Maximum Pressure.	Number of Expansions in Length of Gun.	Initial Velocity.	Vis Viva, or Energy at Muzzle.	Vis Viva per Lb. of Powder.
	Foot-tons per square in.		Feet sec.	Foot-tons.	
85.3 Pebble	63·7	4·6	1,348	8,831	68
32.6 Pebble	46·3	5·1	1,364	9,492	79·1
20 Pebble	27	5·4	1,341	8,784	73·2
27.5 Pebble	18	5·9	1,272	7,863	71·5
25.3 Pebble	21	5·8	1,350	5,160	73·7
21.6 R.L.G	51	6·7	1,318	4,824	80·6
19.7 Pebble	15·4	6	1,413	2,492	71·2
17.3 R.L.G	29·8	7	1,324	2,190	73
15 U.S.Pebble	11 to 12	11·7	1,520	17,323	86·6
15 L.G[1]	?				
8.7 L.G	?	13	1,579	1,150	71·9
10 L.G[2]	?				
8.8 L.G	?	12·2	1,690	626	62·6
4.4 L.G	?	24·5	1,213	511	102·3[2]

in each case for sustaining the extreme force of the charges used; and annexed to each is a longitudinal section of so much of the bore as is occupied by the powder when in its place. Several other particulars are given which will speak for themselves.

[1] Proof charges.

[2] 50-lb. expanding shells fired from rifled 32-pr.

The first gun referred to in the Table is that great piece of ordnance which has been facetiously nicknamed the "Woolwich Infant." This 35-ton gun was not put in hand till there had been official deliberation as to how it should be constructed. Full details of the inquiry instituted may be found in the Report of the Ordnance Council on the Proposed 35-ton gun Competition,[1] which assembled at the War Office on the 4th of May, 1870. The Council consisted of nine military and four naval officers of high rank, with a single civilian, Lord Northbrook, the Under-Secretary of State for War, as president. Sir Joseph Whitworth, Bart., Sir W. Armstrong, C.B., and Colonel F. A. Campbell, R.A., Superintendent Royal Gun Factories, were examined as witnesses. The Council went fully into various questions, particularly such as relate to the strength of wrought iron and steel; for it was assumed from the outset that the sole difficulty to be overcome was that of making the gun strong enough. A glance at the figures in Table II. (p. 194) will show what pressure this gun will have to sustain with the 110 lbs. charge which is to be adopted for it. It is only about two-thirds what the 9-ton 8-inch guns proved able to stand, when R.L.G. powder was used.

It appears from this report that the Council, very properly, sought information on certain points of primary importance from the Committee on Explosives, then at work at Woolwich with the chronoscope and pressure gauges. Out of a series of pertinent questions the Council sent to the Committee, two or three may be quoted,[2] in order to mark with distinctness the actual state of knowledge on the general subject which at that date, June, 1870, was officially recognised.

"*Q.* Given a bore of 15 feet long, and a shot of 600 lbs., would a 10-inch, 11-inch, or 12-inch bore, probably, burn most powder?—*A.* The Committee have had no experience with guns of so large a size, but they consider there can be little doubt that a gun having a bore of 180 inches in length, firing a 600 lbs. shot, will burn more powder with advantage in a 12-inch calibre than in one of 11 inches or 10 inches."

"*Q.* Given the charge of powder, say 80 lbs., would it, probably, strain the gun most in a 10-inch or a 12-inch bore?—*A.* Upon this point the Committee are not yet in a position to offer a decided opinion, in the absence of direct experiment."

"*Q.* Are the exact determinations of pressure likely to lead to any modification of external form and distribution of metal?

[1] Parl. Pap. 308. House of Commons, 27 June, 1870. [2] *Ibid.* p. 17.

—*A.* The Committee do not anticipate that any alteration will be necessary in the external form of heavy muzzle-loading rifled guns (wrought-iron)."

In reply to a request for general information on any other subjects that might occur to the Committee, the answer is "the Committee are of opinion that, when a suitable powder has been determined upon, the weight of the gun of the present Service construction will depend mainly upon the power of controlling recoil."

It would appear, from these concise questions and candid answers, that the art of constructing ordnance, even at this recent date, was not far advanced in theory.

The 35-ton gun was first made with a calibre of $11\frac{1}{2}$ inches, and was subsequently bored out to 12 inches. How far the gun is to be considered a success remains to be seen. It will be noticed from Table III., that the thickness of the walls of this gun is 22 inches, and that the walls are wholly of coiled wrought iron, except the thin tube of steel inside. Now the circumference of the 12-inch bore is 38 inches, and the outer circumference is 176 inches, so that the inner steel tube would have to expand considerably before it could derive the least support from the outer rings of the cylinder, which lie 22 inches from the inner surface. Again, this gun has been fired with 130 lbs. of powder, which caused a strain of 63·7 tons per square inch, enough to crack the inner tube, if it did not otherwise hurt the gun. But this excess of charge and pressure was worse than useless. The proper charge appears to be about 110 lbs., and with this a pressure of 18 tons is all that it will have to bear. To sustain such a pressure an enormous mass of 22 inches of expensive wrought iron cannot surely be necessary. The 8-inch guns have walls only $13\frac{1}{2}$ inches thick, and this was ample to bear a pressure of from 25 to 30 tons. They never failed under it when tried for thousands of rounds, before pebble powder did away with the occasion for it. The weight of metal in the gun could not be spared, for it was wanted to prevent inconvenient recoil. But no skilful engineer would employ a costly metal for mere dead weight or ballast.

By far the most expensive part of wrought-iron guns is the external jacket and trunnions. There is no reason why this exterior part should not be of cast iron instead of wrought iron. In the latter material it cannot be made for less than from £130 to £150 per ton, finished weight. As a hollow cylinder, it would be easy to cast, and probably might be obtained for a ninth part of the price. Without this external jacket there is more sub-

stance of strong material than there is in the smaller gun, which has been proved to be equal to half as much more work as the large gun has to do. In addition to this, it is a question worthy of being considered, whether good cast iron would not be in itself a perfectly suitable material to employ, where, from its position on the exterior of the cylinder, far removed from the centre of the radial lines of force tending to burst it open, its natural elasticity could not be severely tried, but where its even greater force of rigidity or incompressibility would be a valuable adjunct, if needed, to support the more elastic material it encloses. In this way probably half the thickness of wrought iron might be dispensed with, and a simple casting be substituted. If this were done, possibly half the cost of the new guns might be saved, and more of them might be added quickly to the service.

A short time since, the Author ventured to suggest this to the War Office, and he pointed out his reasons. The reply was, that the idea was not novel, that it had been considered, but it was "not thought desirable to employ cast iron for heavy guns." The fact is there exists, in the minds of the War Office officials, a fixed and settled dislike to the use of cast iron in any way for ordnance. It has been pronounced a weak and uncertain material. This has been so often repeated, that almost every one in England has become convinced of it. Yet it may be worth while to find out if there are substantial reasons for the belief, or whether it may not, after all, be a mere prejudice, which naturally arose out of the long-continued obstinate use of powder that ought never to have been employed for cannon of large size.

In America the metal of the cast-iron guns is no better than that supplied from such foundries as the Low Moor, the Gospel Oak, and the Carron Works. The trial which has been made of the material in the United States has been on a scale beyond all comparison greater than anything attempted in this country; but there they have wisely employed good powder. Some years ago one of the 15-inch American guns was bought and tried at Shoeburyness. It threw round steel shot of about 480 lbs. These were fired with 50 lbs. of R.L.G. powder, and afterwards with 100 lb. charges of American powder. It was tried against the Warrior target with 8-inch iron plates; and at short ranges it punched out a piece of iron the size of the large shot (14·85 inches in diameter), and carried it clean through, making a hole in what represented the inner skin of the 'Warrior,' just 3 feet 3 inches in diameter. The velocity of the shot as it left the gun was measured, and its force

may be compared with what the 500-pounder wrought-iron gun produces:

Cast-iron	480-pounder	.	Velocity 1,538 ft.	.	Energy 7,863 ft.-tons.
Wrought-iron	500 „	.	„ 1,315 ft.	.	„ 6,415 ft.-tons.

The English gun is made of 25 tons of wrought iron; the other of 19¼ tons of cast iron. Every hundredweight of wrought iron gives less than 13-foot tons of projectile energy; and the same weight of cast iron gives nearly 20½-foot tons. In short, with 23 per cent. less metal, and that metal cast iron, there was upwards of 22 per cent. more projectile energy than is obtained from the English gun.

One of these 15-inch guns was fired in America[1] as rapidly as it could possibly be loaded with the heavier charges:

12	rounds	with	from 40 to 50 lbs.	powder,	and	shells of 350 lbs.	
129	„	„	50 to 55 lbs.	„	„	round shot 434 lbs.	
4	„	„	60 to 90 lbs.	„	„	„	„
125	„	„	100 lbs.	„	„	„	„

After this the report of the Chief of Ordnance, War Department, for 1868, states that "there is no enlargement of the bore from firing, and the metal had not been cut away by the powder. The gun appears to be perfectly serviceable in every respect." (Rep. p. 163.) At 32° elevation, with 100 lbs. charge, the range was 7,732 yards. More than one hundred of these guns have been made, and the service charge now adopted is 100 lbs. Not one by Rodman, who designed them, has ever burst after being admitted into the service, although one or two failed in the proof, from, it is alleged, defective manufacture. One has stood 868 rounds. The thickness of metal round the cartridge in the 20-inch American cast-iron guns is exactly the same as in the English 35-ton rifled gun. Shot of 1,100 lbs. fired with service charges of 200 lbs. of powder ought to be a good test of the material,[2] and at 25° these guns have a range of over 8,000 yards. Since 1863 the Americans have also rifled many of their large cast-iron guns. One of these 12-inch rifled guns was fired without injury—

107	rounds	with	from 35 to 85 lbs.	of powder,	and	expanding shells of 477 lbs.
341	„	„	35 to 80 lbs.	„	„	shot of 620 lbs.

Another of these 12-inch rifled guns is stated to have been fired

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[1] Most of the facts relating to the endurance of the American guns are taken from the published Report, dated February 25, 1869, of a Joint Committee on Ordnance, appointed in 1867 by the Senate and House of Representatives, U.S.

[2] These 15-inch and 20-inch cast-iron guns have been introduced into the Russian Service. At first they were purchased in America, but they have since been cast at Perm and at Petropaulovski.

390 rounds, with about 600-lb. shot[1] and 55-lb. charges, without being injured. The service charge is from 60 lbs. to 70 lbs. of powder and 620-lb. shot.[1] The thickness of metal round the charge is 17½ inches; in the English 600-pounder it is 20½ inches.[2]

All the Dahlgren navy guns were cast solid, like English guns, and they are said to have been more satisfactory than the Rodman guns, which were cast hollow and cooled from the inside. An official Report of Admiral Dahlgren to his Government, in 1864, states, "In trials made to test the strength of the 9-inch and 11-inch [solid cast guns], no gun has ever fallen short of 1,500 rounds when fired with the charges for which the cannon was intended, and I feel no doubt that if the firing had been continued with service charges, the guns would have gone to 2,000 or 2,500 rounds. This was never done, because no probable exigency would ever have made such a demand on a single gun; extreme charges were therefore substituted" "One [of the 11-inch guns of 7 tons] was used for target practice against iron plates with solid shot [170 lbs.] and charges increasing to 30 lbs., to the extent of 200 fires, and was in good order when I left it." (Rep. p. 98.) "Hundreds of these guns have been cast and carried by vessels second to none of their class; in no one instance has a single 9-inch or 11-inch cannon been burst on shipboard, or a man hurt." (Rep. p. 99.) Two of the 11-inch 7-ton guns endured each 4,250 rounds, and two of the 10-inch 5-ton guns were tested up to 4,082 rounds each without failing: the charges used were chiefly 18 lbs. of powder and solid shot of 130 lbs. One of the 7-ton 11-inch guns was fired 1,300 times with 132-lb. shell, and about 650 times with 170-lb. solid shot, in all 1,950 rounds, with full service charges, without being hurt. A Report from the Chief of Ordnance, War Department, (U.S.), for 1868, states, in reference to the cast-iron guns, "no other [foreign] heavy guns have endured such proof or performed so much work as these guns have done;" and he adds, "their cost is less than one-seventh that of steel or

[1] The initial velocity obtained with 70 lbs. is 1,183 feet (Professional Paper, No. 21, of the Corps of Engineers, U. S. Army. Washington, 1871), and the "remaining energy," at a range of 2,000 yards, is no less than that of the service shot fired from the 25-ton 11-inch English gun with full battering charges of 85 lbs. The 620 lb. 12-inch shot being nearly as heavy, in proportion to its sectional area, as the 11-inch 535-pounder, loses only about 155 feet per second in 2,000 yards, so that it has a remaining energy at that distance of 4,542-foot tons, or about the same as that of the 11-inch shot, which loses 209 feet per second owing to its higher initial velocity.

[2] *Vide* Appendix, Note 4, Rodman hollow cast guns.

wrought iron guns per pound." (Rep. p. 164.) English as well as American wrought-iron guns have been tried there. Two of the Whitworth built-up 80 pounder guns are reported to have become disabled in actual service, from the stretching of the inner tube, after only about 110 rounds.

It further appears that the Americans long ago set to work to rifle all their old service guns. General Ramsay in his evidence before a Committee of the Senate in 1864, states, "With regard to the old guns forming a portion of the armament of the fortification, we are now rifling every gun along the seaboard. . . . . Experiments have shown that the 24 and 32-pounders have sufficient endurance without going to the expense of banding [with wrought iron]. . . . . We are enabled to make reliable rifled guns, even from those originally smooth-bore, as, for example, a third class 32-pounder gun, rifled by Captain Parrott, and fired with his own projectile, 64 lbs. (double the weight of the 32-lb. ball) and with 6 lbs. of powder, withstood 1,000 rounds. This gun was not banded; its tenacity was not more than 16,000 or 20,000, the standard being about 30,000 lbs. It is doubtful whether this gun, before being rifled, would have shown greater endurance with its own proper service charge with round ball. We consider a gun a good gun that will stand 1,000 rounds." (Rep. pp. 202-203.) The system introduced in 1861 was one which several years previously had been tried extensively by the English Government without a failure, and although never adopted, has to this day never been rejected.[1]

It is true that great numbers of the large 'Parrott' rifled guns burst during the American war; but, when it is observed how they were constructed, this is not to be wondered at, as they were made to do more than is attempted in this country with wrought-iron guns of equal weight. Figs. A and B, Plate 24, represent one of these 250-pounders and also a 100-pounder. It will be seen that lengthwise the light cast-iron body had no support whatever; and that, for about 12 inches in the rear of the trunnions, the cast iron had the whole work to do laterally. The wrought-iron band outside could not prevent the inner rings of the cast metal being stretched beyond the limits of its elasticity; and consequently the guns of large size, fired as they were with very severe charges, proved an utter failure. However, out of some thousands of rifled cast-iron guns, strengthened and unstrengthened, only three of less

[1] *Vide* Appendix, Note 1, Official Report on Mr. Bashley Britten's rifled cast-iron guns.

size than 100-pounders failed. One 30-pounder Parrott gun blew its muzzle off at the 401st round; another 30-pounder blew the breech out at the 2,900th round; and the other burst at Morris Island, as it was being fired the 4,606th round, when it was bombarding Charleston at a range of over 7,000 yards.[1]

Cast-iron ordnance has had a great trial in America over many a bloody field, and not on the practice-ground, where the men get under cover; and the soldiers and sailors who have risked their lives in using such guns are content to go on doing so. In the Prussian service the old 24-pounder cast-iron guns (74 inches long) have been converted into rifled breechloaders without being strengthened, and were employed in the late war as siege guns. At Paris, two batteries of six guns each, fired nearly 4000 rounds, and gave perfect satisfaction. Lead-coated shot of 65 lbs., and shells of 55 lbs., were used. The weight of each gun was 27 cwt., just over half the weight of the English 32-pounder, the thickness of metal round the charge is 5 inches, and at the muzzle about $2\frac{1}{4}$ inches.

With regard to English cast-iron guns, it was stated in a Report of the late Ordnance Select Committee in 1863, when the gunpowder in use was even far more violent than R.L.G. powder, and long before pebble powder was dreamt of) that they "must avow a considerable mistrust of cast-iron of the quality turned out by English foundries." (p. 15.) At the beginning of the same Report, it is said that the mean tensile strength of forty-two samples of Low Moor cast-iron, supplied by Messrs. Hood, was ascertained to be 12·71 tons per square inch. Now this happens to be fully up to the standard which was accepted in all the American foundries. Therefore there does not seem to be any ground for this distrust, which, coming from such a quarter has had great influence. The fact is, the British artilleryman did all he could to spoil the guns before taking them into use. No gun was admitted into the service till it had been fired two rounds with projectiles and wads, and extremely heavy charges. Some of these proof charges are represented in Table III., p. 196. It was not known, when this was done, what the effect really was of increasing the charges above a certain limit, in proportion to the calibre of the guns and the 'local pressure,' as it is termed, which arises when long cartridges are used. In the trial of the 35-ton gun, Table II., p. 194, it will be seen that an increase of only 18 per cent. above the proper charge causes upwards of three times as much pressure. In the following

[1] *Vide* Appendix, Note 2, Large Parrott Rifled Guns.

statement the proof charges for the old cast-iron guns are, for comparison, placed side by side, with the service charges for the modern wrought-iron guns of similar calibre :—

Proof Charges of L. G. Powder.			Service Charges of Powder.			
	Cartridges.			Cartridges.		
Cast-iron.	lbs.	Length. inches.	Wrought-iron.	lbs.	oz.	Length. inches.
12-pounders.	12	19·6	12-pounders.	1	8	7
				1	12	
24 „ .	18	20·4	20 „ .	2	10	7·2
42 „ .	25	19·3	40 „ .	5		8·6
8-inch . .	28	16·3	(B.L.) 7-inch	12		6·4
6·4-inch .	21½	20	6·4-inch .	8		7·7

The records of the Woolwich Proof Department show that out of the last 3,300 cast-iron guns supplied to Government by private English foundries (not including the guns attempted to be made at the Arsenal Foundry), only seven of the whole number failed. If the pressure these guns were subjected to, from the enormous proof charges of the old quick L. G. powder, were measured, it might perhaps modify the notion that the iron is a "weak and uncertain" material. It would show that before the guns were taken into use, they were strained with a pressure nearly, if not quite, equal to that produced by the battering charges of pebble powder in some of the monster wrought-iron guns of three times their weight. Indeed, it is probable that any one of the proof charges above mentioned produced a greater pressure per square inch than the charge of 110 lbs. of pebble powder on the 35-ton gun.

At the present time, it is not known what pressure the cast-iron guns have to bear in firing the common service charges; and what perhaps may seem more strange is, that this is not allowed to be ascertained. Some months ago the Author asked permission to have these pressures determined by the new instruments in the public service; and he offered to bear all the cost of the experiments, but this offer was briefly declined.

It is not the object of this Paper to advocate the exclusive employment of cast iron for large ordnance. The foregoing facts have been adduced chiefly to show, that good cast iron is a material which may, with propriety, be largely employed for the external parts of guns, where its natural deficiency of elasticity

[1] From the evidence of Lieut.-Col. Laidley, before the Joint Committee on Ordnance, appointed by the Senate and House of Representatives, U.S., it appears that the standard proof of 10 lbs. of American cannon powder with 64 lbs. solid round shot in the 8-inch smooth-bored gun, caused a pressure of 18 tons per square inch (Report. p. 29).

would not be tried. If a burdensome and unnecessary expenditure of public money may thus be averted, it is surely worth doing.

II. The second division of the subject has now to be treated, viz., as the new ordnance is at present designed, are the power of the charge and the controlling forces in the gun rendered as fully available as they might be?

On the strict economy of these forces really hangs the great question of the ultimate power attainable with artillery, and with it the relative superiority of the means of attack or defence. It has been mentioned that when the Council of Officers met to consider the scheme of the 35-ton rifled gun, they inquired of the Committee on Explosives, whether a larger or a smaller bored gun would burn most powder. It is a remarkable fact that the power of burning large quantities of powder has long been, in this country, the recognised criterion of a good piece of ordnance. This alone indicates the unsatisfactory treatment the subject has received. It is not usual to judge of the merits of a steam-engine by its capability of consuming large quantities of fuel: the best steam-engine does most work with the least fuel; why not the gun also? The value of the gunpowder saved may be of little importance, but every lb. consumed produces its effect on the gun and on the carriage, if not upon the projectile. On looking, then, once more to Table III., p. 197, it will be observed that while the wrought-iron Woolwich guns produce from 73 to 80-foot tons of projectile energy with every lb. of powder in the battering charges, there is another gun (No. 4) which, although not nearly so long, yielded no less than 102·3-foot tons of energy per lb. of powder of the same kind. If the Woolwich guns did relatively as much as this, they would be nearly 35 per cent. more powerful weapons than they are. What was done by this small gun might also be done by larger ones. In fact, the principle carried out on a larger scale is found to produce still greater results.

It is proposed, therefore, to examine critically the five guns, representing distinct principles in design, severally shown by Figs. 1, 2, 3, 4, and 5, Plate 24.

Fig. 1 is a section of the Whitworth small-arm rifle. Fig. 2 shows the general proportions of the Woolwich 500-pounder 11-inch gun of 25 tons. Fig. 3 is the 15-inch American cast-iron gun. Fig. 4, a rifled 32-pounder cast-iron gun, representing the

system which was tried in England, and was subsequently adopted, with a modification, in the service of the United States. Fig. 5 is a proposed 15-inch rifled gun of a different construction, but intended to carry out on a greater scale the same principles which are to be found in the 32-pounder.

Fig. 1. *The Whitworth Small-arm.*—As an instrument, without reference to size, there is little doubt which of these five representative weapons is theoretically most perfect. The small arm with 70 grains of powder, controlled by about 4 lbs. of iron, can effect the penetration of more than 2,000 yards of the atmosphere in the range of its projectile over a plane. Nothing approaching this can be done with any cannon in existence. If all the conditions on which the power of the small arm depends could be preserved, and be magnified into a 12-inch gun, its bore would require to be 78 feet long, and the charge would have to be 130 lbs. of powder, and a shot 980 lb. Something approaching the proportions of the charge have been used in the 35-ton gun; but its bore is only 13½ feet, instead of 78 feet long. If the Whitworth rifle were cut down to the same proportions as the 11-inch Woolwich gun, it would then be but a pistol. Looking at the drawing of the Woolwich gun, what is it but a monster overloaded pistol.

Ever since the introduction of the Minié rifle, it has been the custom to talk of the advantages of 'small-bored' guns. But the principle of the Minié rifle has nothing whatever to do with the size of the bore. The Whitworth, or the Chassepot, does not carry a yard further than the Enfield rifle because the bore is smaller; but simply because the bullet is solid, longer, and heavier, and because there is sufficient length of barrel for the charge to expand as far as it has power to accelerate the velocity of the bullet, giving the mass of matter in the bullet full time to absorb moving force. The bore of the small arm has to be reduced, because otherwise it would be too large and powerful a gun for a man to fire from the shoulder. If, then, this is the most perfect firearm, it is desirable to ascertain which of the other weapons best fulfils the same conditions.

Fig. 2. *The* 11*-inch small-bored Woolwich* 500*-pounder.*—The first thing that catches the eye on looking at the section of this gun is the large space occupied by the charge. All the power of the gun is derived from the expansion of the charge; but little length is left in the bore available for this expansion. Does this resemble the small arm? In one case the charge can expand into 27 times its original volume, and in the other only 5·8 times. It must

also be observed that the chronoscope experiment, detailed in Table I. p. 192, showed when the charge in the experimental 8-inch gun had expanded, even to a rather greater degree than this, it had still remaining a force of 150 atmospheres; and it is evident that, so long as there was any greater pressure behind than there was in front of the shot, this was capable of adding velocity.

The reduction of the calibre involves two important consequences. Projectiles of great length necessarily present a smaller area to the action of the charge; their resistance to the power which has to move them is therefore as their weight in proportion to the area of their section. This would not matter if there were sufficient length of space for the shot to move through in the bore; but it is clear that the more the pressure has to labour, in overcoming the resistance offered on the narrow area of the heavy long projectile, the more time it requires, and the longer must be the course needed for the shot to travel while the speed is being got up. But the small bore lessens the length of the shot's course, in consequence of the necessary charge of powder taking up so much of the gun's length. And the longer the cartridge is, the less of its power can it exert, except as a force to burst the gun open. Extend the principle of the small bore to an extreme, and nearly the whole of the force of the charge would be exerted laterally on the gun; so that a comparatively small resistance at the end of the column would be sufficient to close it up. In order to attain the required velocity, in such a short space, it is necessary to employ extreme intensity of pressure; but, while this tells upon the gun, it adds comparatively little to the power of the shot; for, although the force is sustained by the continual liberation of the gas as the charge burns, the time it has to act on the projectile is circumscribed, and time is quite as essential as pressure. It is only as the gas itself acquires motion, through the mutual repulsion of its atoms, that it becomes a force which can impart *vis viva;* and the matter in the projectile can acquire *vis viva* no faster than the laws of nature have prescribed.

When the unwelcome fact was plainly revealed, that the English plan of working guns with an extreme pressure rapidly destroyed the interior of the bore, a slower-burning powder was resorted to, and with manifest advantage. Greater power in the shot was gained simply by "losing time" in the gun, or, rather, employing it. Larger charges could be used, and they caused only half the strain on the bore. Still, this was but an expedient to save the guns; it rendered them as instruments really less correct than they were before. The more sluggish powder

necessarily requires a longer time and a greater space for the development of its force; yet the larger charges take up so much of the gun's length, that the shot loses the benefit of length of stroke from the charge. As an expedient, the adoption of slow-burning powder is, of course, beneficial; but it is not in small-bored guns that the full benefit of this improvement can be realized. This is evident from the records of the chronoscope experiment, in Table I. (p. 192). If the gun there referred to had been considerably shorter, the quick powder would have given better results. As it was there was more waste of power at the muzzle from the slow powder than from the other. The principle involved in the adoption of slower burning powder is, therefore, absolutely inconsistent with the principle of small-bored ordnance. The essence of the improvement lies in the gain of power at the expense of time; but in cannon of small calibre force must be won quickly, for there is no opportunity of gathering it gradually.

For artillery of small calibre the evils of the reduced bore are not felt, because quick powder can be used with advantage, and a certain cylindrical length of shot is needed to secure steadiness in the passage through the gun so as to ensure accuracy of flight. As the size increases, the weight of shot growing in the ratio of the cube, the evils become magnified, so that in the case of the 35-ton guns they are found to present insurmountable obstacles to further progress. There is no test of the correctness of principles like that of attempting things on a large scale. The small Armstrong guns were a tolerable success, but the large ones failed. The small Whitworth 12-pounder worked admirably, but it is doubtful if large guns on the same plan have been satisfactory. The smaller Parrott guns did all that could be desired, but the large ones turned out failures. And the smaller Woolwich guns are evidently superior to the larger ones.[1] The 35-ton guns, even when bored out as much as their substance at the muzzle will allow, cannot burn the charge for which they were designed; and probably $\frac{2}{3}$rds of their massive strength is wholly useless.

The evil of the small calibre is not confined to diminishing the capacity for expansion of the charge; another objection has practically asserted itself. The effect of cartridges from 2 to 3 feet long, such as some which are used, is to engender an enormous amount of what is termed 'local pressure' on the gun at each end

[1] See Table V., page 227, also Note *Ibid.*

of the charge. When a long column of powder is ignited, the gases first disengaged rush through the interstices of the powder, and, having so acquired *vis viva*, they strike the shot at rest. Here, till the shot moves, they meet with a check powerful in proportion to the weight of the shot represented in its area of section. The elastic gas is therefore thrown back in its course, and deflected outwards on the sides of the gun; the *vis viva* of the gas becomes changed into pressure, and fresh streams flowing up to this point cause compression, and compression naturally produces greater heat and quicker combustion. All the experiments of the Committee on Explosives show this to be the inevitable concomitant of long cartridges. Captain A. Noble has stated,[1] in a lecture at the Royal Institution, last year, that by the explosion of a large quantity of powder in this long form "the pressure of the gas is liable to be locally exalted, even above its normal tension, [about 42 tons per inch], in a perfectly closed vessel, and this intensification of pressure endangers the endurance of the gun, while detracting from the useful effect." He adds, as the result of experiments, that "in all cases it is desirable to have the charges as short as possible, and the cartridge so lighted as to reduce the run of the gas to its shortest limit." These observations, coming from one who has probably had more experience than any other authority, have an important bearing on the remarks which have been made with reference to the Woolwich system of ordnance generally. It is difficult to understand how small-bored guns could use anything else than long cartridges; it is a distinct feature appertaining to the system; and to condemn the cartridges is to condemn the principle of the guns.

Fig. 3. *The 15-inch cast-iron American gun* has now to be referred to. This gun is 18 inches longer in the bore than the 11-inch 500-pounder shown by the side of it, and it weighs about 5 tons less. Although entirely of cast iron, it has only 16 inches of metal round the cartridge, while the wrought-iron English gun has 21 inches, or 5 inches more. The large 20-inch American guns are on the same model, and the thickness of their walls is the same as that of the 35-ton English gun. The American soldiers stand fearlessly beside these guns, when fired with their respective charges of 100 lbs. and 200 lbs. of powder. When the 15-inch gun was tried at Shoeburyness against plates, it was found to deliver its shot with greater force than any gun in the English

[1] *Vide* Proceedings of the Royal Institution of Great Britain. Vol. vi., p. 283.

service, but it was not equal to rifled guns in regard to penetration. The Americans contend that the racking effect, or the power of large shot to break up defensive works, by smashing and shaking an edifice by a blow of extreme force, is of greater value than mere penetration. British artillerists do not think so. If, however, one of the 20-inch cast-iron guns had been tried, it would have been found that, both in regard to racking effect and penetration, there are no guns in the British service so powerful up to probably 2,000 yards. According to American measurements, the initial force of the 1,100-lb. shot is considerably more than twice as much as is obtained from the 35-ton gun firing 130 lbs. of powder and subjecting it to a pressure of 63 tons per square inch, or than even wrought iron could be trusted with.

By analysing the conditions under which the charges are applied, it will be seen why the weak American cast-iron guns produce so much more power than is obtained from wrought-iron English guns. From the drawing it may be possible to explain that the charge of 100 lbs. of powder takes up less length of the 15-inch bore than the change of 85 lbs. does in the 11-inch. It may be assumed that when the charge is wholly turned into gas, it would exert an equal pressure in every direction. Projectiles are moved by a force, greater or less, in proportion to the quantity of powder exploded against the area of section presented to the pressure. In the same way, the pressure is curbed by the amount of resistance which the projectile offers from its weight in proportion to its area: the greater the area, so much less pressure per square inch would move it. These conditions, then, under which the charges act in the two guns, may be compared as follows:—

15-Inch Gun. Cast Iron.

	Per inch of area.
Charge, 100 lbs. . . } Shot, 480 „ . . }	Equals ·565 lb. powder to propel 2·54 lbs. shot.

11-Inch Gun. Wrought Iron.

Charge, 85 lbs. . . } Shot, 535 „ . . }	Equals ·895 lb. powder to propel 5·7 lbs. shot.

The 11-inch projectile therefore offers nearly twice as much resistance as the other to the pressure. Far less intensity of force is consequently sufficient to start the 15-inch shot, and it gets under weigh when but a small proportion of the powder has ignited, so that the gas cannot accumulate against it to cause great strain.

In the same way the charges in the 20-inch cast-iron gun may be compared with the extreme charge of the 35-ton gun, as follows:—

20-Inch Gun. Cast Iron.

Per inch of area.

Charge, 200 lbs. . }
Shot, 1,080 „ . } Equals ·637 lb. powder to propel 3·3 lbs. shot.

11½-Inch 35-Ton Gun. Wrought Iron.

Charge, 130 lbs. . . }
Shot, 700 „ . . } Equals 1·15 lb. powder to propel 6·2 lbs. shot.

It will be seen, from this analysis of the conditions imposed on the charge, why the large shot may acquire more force without so much strain on the gun. There is, however, another important point to note, viz., that the large calibre of the American gun allows the gas to go on urging the shot while it is expanding into nearly eleven times its volume; whereas in the English gun all the power beyond the sixth degree of expansion is wasted in the air.

Although the American guns afford a good example in regard to economy of force, still, as weapons, they may be considered defective in three respects:

(1). As smooth-bored guns they cannot command such precision as rifled guns at great distances.

(2). The round shot are not heavy enough, in proportion to their bulk, to enable them to retain their force. They may be safely fired with charges that will impart great velocity to them, which is valuable for short ranges; but in a considerable flight, the resistance of the air, which is in proportion to the square of the velocity, quickly destroys the shot's power.

(3). A probably still greater objection to spherical projectiles is that they are naturally weak from their form. The particles do not support each other in their cohesion, as in cylindrical shot. Elongated shells can be fired through thick iron plates without breaking, against which solid spherical projectiles, even if made of steel, break up, and lose much of their effect. This was found to be the case with the steel round shot fired from the 15-inch gun against the 'Warrior' target.

It remains to be seen whether the two other guns, now to be examined, do not represent higher principles of mechanical economy than are to be found in either of the designs already referred to, without the sacrifice of any one point of efficiency.

Fig. 4 is a rifled 32-pounder cast-iron service gun of 56 cwt., and Fig. 5 is a proposed 15-inch rifled gun, designed for pro-

jectiles of 1,000 lbs. or 1,200 lbs., embodying the same principles as the 32-pounder, but of different construction. The mode of construction, however, is not to be mixed up with the question of the general design.

This system of rifled ordnance was originally suggested by the Minié rifle, and will be found to embrace the principles of the small arm more fully than the other guns. Instead of employing a small bore in proportion to the gun's length, as in the case of the Woolwich system, a large calibre is preferred; and instead of endeavouring to burn as much powder as can be possibly ignited in the bore, only so much is intended to be employed as can be productive of useful effect without waste. As a cannon cannot have the space for the expansive working of the charge which a small gun with a long barrel has, it is still possible to get this space in breadth. The smaller gun, Fig. 4, was rifled to the Author's design at Woolwich in 1855. It was one of several cast-iron service guns which were extensively tried by the English authorities between 1854 and 1863.[1] The immediate object then aimed at was to improve the efficiency of the old guns. These were rifled with shallow grooves, only about $\frac{1}{10}$th or $\frac{1}{16}$th of an inch deep, so as not to weaken them; and projectiles were used having a sabot of soft metal firmly attached to the base, by a plan which was specially devised by the Author for the purpose,—a plan eventually adopted for all the Armstrong projectiles, and now in general use on the Continent. The construction of the projectiles will be understood from Figs. D. and E., Plate 24. On the gun being fired the sabot of soft metal is upset, and expanded into the grooves, preventing much escape of the gas; and the rifling thus acting only on a yielding metal, the possibility is avoided of the shot overriding the screw, or otherwise getting wedged or obstructed.

At the time this plan was proposed and first tried (1854–5), the Armstrong gun had never been heard of at Shoeburyness.

The usual charge of powder then employed for cannon was about $\frac{1}{3}$rd the weight of the shot. For the rifled 32-pounders the Author proposed only $\frac{1}{10}$th, and for 68-pounders $\frac{1}{12}$th, and even $\frac{1}{15}$th; his principle being to load the guns with "low charges," that is to say, much more shot and less powder. Charges so small had never previously been used, or proposed. From the outset he opposed all idea of reducing the calibre of the guns; on the contrary he has, in opposition to the views of Sir William Armstrong,

[1] *Vide* Appendix, Note 1.

Sir Joseph Whitworth and others, persistently advocated the employment of a large sectional area, as necessary for the proper utilization of the pressure from the charge. But the small bore was pronounced the right thing, and small bores were adopted.

What the Author wished to demonstrate was, that the old guns might, on his plan, be rendered far more efficient, without giving them more to do, or rendering them less endurable or safe. The rifling did not interfere with the use of the old ammunition in store. A trial clearly proved, that the shallow-grooved rifled guns threw the round shot as far as, and with more precision than, the smooth bore.[1] The high velocities and useful work of all the old projectiles, including grape, might consequently be retained, and the greater long range power and precision of the elongated rifle shot be combined in the same guns.

With the "low charges" the rifled 32- and 68-pounders threw capacious shells, 50 per cent. heavier than their round solid shot (and capable of carrying large bursting charges), with far more accuracy and greater force to nearly 6,000 yards than in their smooth-bored state they command with the round solid shot at 1,500 yards. Unfortunately, however, these facts were misinterpreted; they were deemed to prove too much. It was assumed by the Committee that these results could not be obtained without involving "much greater strain on the guns." The Committee judged of the "work done" by the power retained by the shot at long ranges, and not by the energy of the shot at the muzzle of the piece.

It is worth while to examine this point with care, because what was found to be true with these comparatively insignificant 32-pounders and 68-pounders must be just as true of other guns of greater size. If the 32-pounders and 68-pounders could be so improved, why not such gigantic guns as the American 15-inch, and even 20-inch round shot ordnance? The question is — Does a 5-lb. charge, propelling a 50-lb. projectile with a moderate speed, entail more strain on the gun, than the usual 10-lb. service charge driving a 32-lb. shot at a much higher velocity? From the measurements of velocities, which were carefully made and recorded in the official report of the trials, the following comparison is obtained:

Cast-iron 32-pounder.	Initial Velocity.	Vis Viva, or Energy of Shot at Muzzle.
10 lbs. powder, 32 lb. shot, gave . .	1,690 feet per second	= 626·6 foot-tons.
5 „ „ 50 „ shell „ . .	1,209 „ „	= 511·1 „ „

[1] *Vide* Appendix, Note 1, Extract No. 3.

The smaller charge in the rifled gun produced less force by about 18½ per cent., which is inconsistent with the idea of greater strain. There is of course the friction on the rifling, and the power required to give rotation to the shot to be taken into account, but these carefully calculated do not amount to 2 per cent. of the whole. It will be seen by Table No. II., p. 194, that the strain on the 10-inch experimental gun at Woolwich was less from the same charge after it had been rifled than when previously fired as a smooth bore.[1] But if the small charge in the 32-pounder developed so much less force in the projectile than the service charge with the solid ball, it will be asked how are the longer ranges of the 50-lb. shells to be explained. It was owing to the fact, too much lost sight of, that in giving high velocities to any projectile, power is produced which the atmosphere destroys so quickly that it is scarcely available.

The velocities of both the rifled shot and the round shot from the 32-pounder were correctly ascertained, not only at the muzzles, but at the short distance of 30 yards from the guns. In this brief space, the round shot, cutting through the air with enormous speed, lost 36 feet per second of its velocity, but the 50-lb. projectile lost only 9½ feet. At 1,000 yards the time of flight showed, that the velocity of the round shot, though 480 feet more than the other as it left the gun, in traversing this distance had fallen below the other; the time observed gave 970 feet per second as the mean velocity of the 32-lb. ball, and 1,045 feet as that of the 50-lb. shell. Computing, from the respective times of flight, the force or energy remaining in the projectiles after traversing about 2,000 yards, the figures come out—

32-lb. shot, at 1,882 yards . . Mean velocity 856·7 = vis viva 163 foot-tons.
50-lb. rifle shell, at 2,100 do. . „ „ 984·3 = „ „ 336 „ „

So that the heavier projectile, although acquiring less force from the small charge, was not robbed of it by the air to anything like the same extent as the other. Indeed it retained two-thirds of its power for a considerably longer distance than that at which the round shot was found to retain only one-fourth. Greater efficiency therefore was gained, not by giving the gun more work, but by giving the shot less to do in beating the air.

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[1] This may be accounted for by the fact, that the rifled projectiles were $\frac{45}{1000}$ths of an inch less in diameter, so that the work of spinning the shot, at the considerable speed which the rifling in this gun produces, is not equal to the small force lost by this trifling additional escape of gas through windage.

The guns could be rifled at a cost officially estimated at ten shillings per gun, and, by portable machinery, the work could be done without removing them from the batteries where they stood. The rifled 32-pounders proved in the trial to be more powerful than the Armstrong 40-pounders with which they were compared.[1] But notwithstanding the manifest advantages which might so easily, and at so little expenditure, be acquired, the plan has not been used in this country, although in America the system was generally adopted in 1861, and throughout the Rebellion War not one gun appears to have shown want of endurance.[2] It has proved in vain for the Author to point out to the authorities, that in the extensive trial which lasted, or rather languished, over nine years, no failure occurred with any of the guns; and that the phenomena which presented themselves negatived the idea of the guns being overtasked so as to involve danger. The Author has volunteered to pay the cost of the experiments needed to prove, by measurement of the pressures, the advantages that might be secured without adding to the usual strain on the service guns, but this offer has been declined. The public could have lost nothing by such a trial, but might have greatly benefited. The plan of conversion selected instead of this is represented in the Palliser converted 64-pounder gun of 71 cwt.,[3] Fig. C., Plate 24. It will be observed that longitudinally, where the greatest strain falls, the work has still to be done by cast iron, as in the case of the Parrott guns. It has been admitted, both by Major Palliser and Sir William Armstrong,[4] that little strength is added in this direction by the coiled inner tube. This plan was adopted before pebble powder was made, and before any means of measuring the pressures existed. Some hundreds of the old guns have been so converted by Sir William Armstrong and Co., at a contract price which is about twice as much as the guns originally cost, viz., from £125 to £250 each, according to size, and this price is stated to be "unremunerative." At Woolwich the work costs more. The 64-pounders when thus converted are not so powerful as the

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[1] *Vide* Appendix, Note 1. Extract, No. 4.

[2] An official list of all the American guns which burst or became unserviceable between 1861 and 1868 is printed in the Report of the Joint Committee on Ordnance (U. S.) 1869, p. 211.

[3] *Vide* Appendix, Note 6. Conversion of Cast-iron Service Guns.

[4] Report of the Ordnance Select Committee on Coiled Wrought Iron Inner Tubes for Ordnance.—Parl. Ret., 16th March, 1868.

rifled American 32-pounder service guns which are not strengthened. This is seen by Table V., p. 227.[1]

In the course of the trials of the Author's plan, an experiment was made in 1863 which served to illustrate what may be effected by carrying out the principles of economising force,—the subject of this Paper. Two of the rifled 32-pounders and two 68-pounders (service guns) were fired at Woolwich with the charges proposed for service, and with expanding projectiles of increasing weight, till the guns burst.[2] One of the 68-pounders was fired 10 rounds with 90-lb. shot, 10 of 135 lbs. each, 10 of 180 lbs., 10 of 225 lbs., 10 of 270 lbs., 10 of 315 lbs., 10 of 369 lbs., 10 of 405 lbs., and it burst, at last, in firing shot of 450 lbs. Now, with each increased weight of projectile, the penetration into the butt was deeper and deeper, till at length the small charge of $7\frac{1}{2}$ lbs. of powder ($\frac{1}{60}$th) drove the 450-lb. projectile through 20 feet of solid sand and clay; evidencing an amount of projectile force greater, it is believed than was ever before produced with such a weapon, and with such a "low charge" of powder. The proportions of powder and shot to the area of the bore of the gun, compared with the proposed service charges, were—

		Per inch of area.
Service charge, $7\frac{1}{2}$ lbs., shell, 90 lbs.[3]	=	·155 lb. powder, 1·75 lb. shot.
Experimental charge, $7\frac{1}{2}$ lbs., shot, 450 lbs.	=	·155 „ „ 8·73 „ „

The specific resistance offered by the pressure to the 450-lb. shot was more than the resistance to the 700-lb. shot fired from the 35-ton gun, the latter being only 6·73 lbs. per square inch of section, instead of 8·73 lbs. as above. The powder used was the old common quality of the time; quicker and more violent than even the

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[1] The old 68-pounders of 8·12 inches bore are now being converted into 6·3-inch guns, to fire 80-lb. shells with 10-lb. charges, at a cost of £250. The Author's plan rendered them far more powerful as 90-pounders, for only a few shillings. With pebble powder they might, on the same plan, fire shot or shell of 115 or 120 lbs., and be subject to less strain, and so be converted into powerful guns, adapted for all services capable of being performed by weapons of that weight.

[2] This trial was not strictly analogous to the usual trial of smooth-bored guns with heavy cylinders, because the additional weight caused greater expansion of the soft metal as it was employed on the shot, and not only produced more friction on the bore of the guns, but cut off all, or nearly all, escape of gas; whereas, with non-expanding simple iron cylinders windage is always allowed, and when the cylinders are heavy, their less velocity affords more time for the gas to pass out through the windage.

[3] This charge gave a range of 1,000 yards with 2° elevation, and 5,480 yards at 23°, with a mean deviation from the line of aim of 8 yards at the latter distance.

present R.L.G., which has been improved. The rifled 32-pounders did not burst till the charge of $5\frac{1}{2}$ lbs. (or ·172 lb. per inch) was curbed by shot of 165 lbs. weight, or 5·2 lbs. per inch, which is nearly as much as the resistance of the 600 lb. shot in the 12-inch 25-ton gun (5·3 lbs. per inch).

There can be no doubt that, if the strength of these guns had been tested by increasing the charge of powder instead of the weight of shot, they would have burst long before they produced as much penetrating force as they did. There was a small charge; but its power was fully employed. It could go on accelerating the motion of the mass of matter in the projectile, as it expanded to nearly its 28th degree (or so many times its original volume); and the shot had a longer time, because of its weight, to acquire *vis viva* from the gas. Here then, it will be noted, the conditions of the Whitworth rifle (Fig. 1, Plate 24) were nearly fulfilled within the limits of a short cannon, for in the small arm the gas expands 27 times. If instead of the violent powder, a slower burning quality like "pebble" had been employed, the guns would have gone on firing shot of much greater weight before they failed; and those heavier shot would have had more time for taking up force, and would therefore have effected greater penetration. If, then, so much penetration could be effected in sand and clay, the same projectiles would accomplish its equivalent in the air, or in iron plates. It was the proper work of a projectile performed by economy of power, with the smallest means.

These observations have, quite recently (October, 1871), been confirmed by some valuable experiments, of an exact nature, made at Woolwich. Shot of increasing weight were fired from the 10-inch experimental rifled gun, with the usual service charge of 70 lbs. of pebble powder, and the velocities and pressures were measured and recorded. From the ascertained velocities, the Author has worked out, in Table IV., the force or energy imparted to each shot, and the results are instructive.

TABLE IV.

EXPERIMENTS at WOOLWICH, with a 10-inch RIFLED GUN, firing increased WEIGHTS of SHOT with the usual Service Charge, 70 lbs., showing the gain of Power by losing Time.

Projectile Weight.	Velocity.[1] Feet per Second.	Pressure (maximum). Tons per square Inch.	Vis Viva. Foot-Tons.	Vis Viva per lb. of Powder. Foot-Tons.
300	1,521	15·6	4,819	68·8
350	1,423	17·0	4,921	70·3
400	1,351	18·0	5,068	72·3
500	1,209	19·9	5,074	72·5
600	1,128	21·1	5,300	75·7
800	981	20·9	5,374	76·8
1,000	884	22·1	5,425	77·5

[1] At 50 yards from the gun. These figures were furnished to the Author by Capt. Noble, R.A., by permission of the War Office.

There is distinct evidence in these figures of the sacrifice that has to be made to obtain high velocities in projectiles. In this gun of the ordinary dimensions, the large charge has only space within the small bore for 5·8 expansions. The bore, although 145 inches long, has little more than a length of 119 inches in which the shot can gather velocity. The speed of 1,521 feet per second is attained by the 300-lb. shot; but, in doing this, every lb. of powder only produces 68·8 foot-tons of useful work. With heavier shot and a lower velocity, as much as 77·5 foot-tons per lb. was produced; and, instead of a force of only 4,819 foot-tons, the same charge and the same gun yielded 5,425 foot-tons, including so much more punching power. The question of calibre however here obtrudes itself. To get a shot of 1,000 lbs. weight into this 10-inch gun, it has to be 50 inches long. This involves serious difficulties in regard to the action of the rifling. Besides, the resistance such shot offer, in the column of weight to area presented to the pressure, is no less than 12·82 lbs. per square inch. This, in so short a gun, is obstructive resistance. It remains, therefore, to consider what may be done by employing projectiles of such a weight as 1,000 lbs., and adapting them for a gun of 15 inches calibre instead of 10 inches. They will then no longer offer a resistance of 12·82 lbs. per inch to the charge, but only 5·66 lbs.

Fig. 5, Plate 24, represents a proposed 15-inch rifled gun, designed for projectiles of 1,000 lbs. or 1,200 lbs. The object is to get great results from "low charges," without resorting to the

employment of extreme intensity of force, which is better avoided if it can be dispensed with; better for the guns, as involving less wear, as well as for the carriages, the platforms, and everything affected by the violence.

This 15-inch rifled gun would be a low-pressure gun, and there is no reason why ordnance of almost any larger size should not be made on similar principles. Guns of 20 or 25 inches calibre might be so constructed at a moderate cost. The charge of powder shown in its place is 75 lbs. Slow burning pebble powder would of course be used, not the destructive R.L.G. The 1,000 lb. shot in such a gun would not oppress the charge with much more weight per inch than the 165-lb. shot of the same character, fired from the rifled 32-pounder in the trial just referred to, when the old quick-lighting and quick-burning powder of the service was used; the relative proportions per inch of sectional area being—1,000 lbs., 15-inch shot = 5·68 lbs. per inch; 165 lbs., 6·4-inch shot = 5·2 lbs. per inch. Such guns, therefore, would not require to be made so strong as the wrought-iron small-bored guns. It is indeed a question whether such charges would cause more strain than this gun would endure with safety, if made wholly of good cast iron.

By the use of slow-burning powder and expanding projectiles, rifled 12-inch guns wholly of cast iron have been employed in America, with more severe conditions than are proposed for the 1,000- or 1,200-pounder compound gun. They may be compared as follows:—

American Cast Iron 12 Inch Rifled gun. Powder, 55 lbs., Shot, 620 lbs. . . .	= Powder ·487 lb., Shot 5·5 lbs. per inch of area.
Proposed 15 Inch Rifled gun. Powder, 75 lbs., Shot, 1,000 lbs. .	= Powder ·42 lb., Shot 5·68 lbs. per inch of area.

With the above more powerful charge, the cast-iron American 12-inch rifled gun has been fired 390 rounds without injury, and charges up to 80 lbs. have been used without bursting the gun. The small charge of only 75 lbs. is suggested for the 15-inch gun, for the simple reason that it is doubtful whether, if it were more heavily loaded, the recoil would not be too great to be conveniently controlled, although the gun weighs about 35 tons.

The general character of the weapon, Fig. 5, in respect to its adaptation for using up, not merely "burning" or igniting its charge, will be at once apparent. It is placed in juxtaposition with the 11-inch English gun (Fig. 2), which is the highest exemplar of the Woolwich system. The following advantages are claimed for the 15-inch gun, in regard to the economical

employment of the power of the charge, and also of the controlling force of the gun:

1. The cartridge is of better form. It is 12 inches long, instead of upwards of 25 inches. The gases are evolved more directly against the projectile, and less against the gun laterally. There is but a short "run of the gas" before it strikes the shot at rest, which Captain A. Noble and the Committee on Explosives have stated to be so detrimental, causing oscillations, or a wave, producing an intensity of "local pressure," at either end of the powder-chamber, sometimes greater than the entire initial force of gunpowder exploded in a compact form. All this is obviated, and consequently there would be less wear on the interior of the bore.

2. The charge can expand into 16 times its original volume, instead of only 5·8 times. It would, therefore, develop, and naturally impart, more force; while in its combustion there would be less smoke or unconsumed products.

3. There is a longer stroke from the charge. The shot is urged through a space of 15 feet, instead of 10 feet; practically, therefore, the gun may be said to be half as long again for doing work, and the shot has more time for acquiring *vis viva*.

4. The 1,000-lb. projectile requires about the same pressure to give it motion as the 535-lb. 11-inch shot; the respective weight or resistance of each to its sectional area being as nearly as possible the same. On the larger shot starting, more room is given for expansion of the gas; this relieves the gun, and prevents the pressure culminating into a strain of severity. Of course the 1,000-lb. shot would not be likely to acquire so high a speed as the lighter one fired with a larger charge.

The English authorities have always made a great point of high velocities—perhaps too great a point. The 11-inch rifled gun cannot command the velocities which the American 15-inch and 20-inch guns do; still the former is said to be the better gun. There is, consequently, something of more value than speed. This something the 15-inch rifle would produce. High velocities are not to be attained without great sacrifices. A shot cannot be made to move more quickly than air can rush into space, without the atmosphere interposing a resistance which, of itself, is greater than arises from the absolute weight of any shot that could be used. The long cylinders fired experimentally from the 10-inch gun, weighing 1,000 lbs., and being 4 feet 2 inches long, offered a resistance on every inch of their sectional area of $12\frac{3}{4}$ lbs; but any shot forced to move above 1,330 feet per second must meet

with a resistance of a full atmospheric pressure, which is far more than 12¾ lbs. When those high velocities are produced, Nature forbids their being used for more than a moment. On the other hand, at a smaller expenditure of means, a greater projectile force may be set up, which the air will not destroy so readily, and which can be employed for a longer time, and be more useful.

Theoretically, the great principle of the rifle is to gain available power in heavy shot at the expense of speed; but to reduce the calibre of guns is practically to curtail the weight of the projectile, and thereby to lose the means of collecting and storing up the energy of the gas. In the small-bored Woolwich guns, power is sacrificed in secure great velocity, which is soon lost.

A careful estimate, based on what is known to take place in other guns under analogous conditions, shows that the charge of 75 lbs. of pebble powder, when turned fully to account as it might be in this capacious 15-inch rifled gun, having a bore 16 feet long,[1] and firing expanding projectiles of 1,000 lbs. weight, would impart to them a velocity of not less than from 1,140 to 1,150 feet per second. This is about 200 feet less velocity than is produced in the 500-pounder 11-inch gun; and the 500-pounder yields less by 190 feet per second than the 15-inch 480-pounder American smooth bore. At a cursory glance 75 lbs. of powder may appear a small charge to produce such a velocity, but it must be borne in mind that it would act in this gun under conditions unlike those applied in any gun of the British service; and it is not of much moment whether a pound or two more or less powder would be needed, as the gun is strong enough for twice the charge if it could be used. Still it may be considered as almost certain, that the quantity of powder stated would be sufficient to impart this velocity or even more, from what has been done with the American 12-inch rifled gun firing similar expanding projectiles of 620 lbs. with 50 lbs. of American mammoth powder, which is perhaps rather less powerful than English pebble. With this gun, the mean initial velocity, in a trial of 75 rounds, was 1,139 feet per second.[2] Here the charge of powder is a little larger in proportion to the weight of the shot than for the 1,000-pounder, it being ·44 lb. per inch of area instead of ·42 lb.; the resistance of the shot

[1] If the proposed 15-inch gun were required to be as short as the present 35-ton guns, probably 5 or 6 lbs. more powder would be required to produce the same velocity.

[2] *Vide* Report of the Joint Committee on Ordnance in the Senate of the U.S., February, 1869, p. 164.

differs but little, being 5·5 lbs. per inch, compared with 5·66 lbs. per inch for the larger gun. As compensation for the rather greater charge, the 15-inch rifle is 29 inches longer in the bore, so that the gas has an available stroke of 29 inches more than in the 12-inch gun. Now this measured velocity of 1,139 feet in the 620-lb. shot exhibits a total energy of 5,585 foot-tons, or 111·7 [1] foot-tons to every pound of powder expanding in the gun 13 times, with a stroke of 150·5 inches. Every pound of powder in the 75-lb. charge for the 15-inch gun would certainly yield considerably more than this, because it would expand in the gun 16 times instead of only 13 times; it would act on the shot with a stroke of 180 inches instead of 150·5 inches; therefore the gas would be worked out more fully, and the shot would have more time for taking up its force, it being the weightier, and having a longer run in the bore.

In the instance of the 32-pounder smooth-bore, 10 lbs. of powder and 32 lbs. round shot give 62·6 foot-tons of energy per lb. of powder. The same gun rifled, firing 50 per cent. less powder and expanding projectiles 50 per cent. heavier than round shot, produced 102·3 foot-tons per lb., or an increase of 63 per cent. The 15-inch American smooth-bore being a longer gun, and the solid contents of the shot being greater in proportion to size than the 32-pounder, gave 78·6 foot-tons per lb. The 1,000-lb. 15-inch rifle shot is upwards of 108 per cent. heavier than the 480-lb. round 15-inch shot; the charge proposed for the former would be worked out to 57 per cent. more expansion, and with 33 inches longer stroke; so that relatively a much greater result may be calculated upon from every lb. of powder. It will be seen from Table III., p. 196, that from the increase of weight in the shot alone, without any more expansion, or longer stroke, or less windage but merely from, "losing time" in the gun, there was a gain of power, equal to nearly 13 per cent., from every lb. of powder fired.

The velocity of 1,140 feet per second in shot of 1,000 lbs. weight represents a total energy of 9,023 foot-tons—a far greater force than is obtained from the 35-ton wrought-iron gun, with the charge of 110 lbs., which is to be adopted for it. It is, in fact, more than this gun produced when fired with 130 lbs. of powder. The 110-lb. charge produces in the 700-lb. shot an initial velocity of 1,272 feet per second, or an energy of 7,863 foot-tons. The

[1] The yield of force in the Woolwich 12-inch rifled guns is only 82·7 foot-tons per lb. of powder.

110-lb. charge has room to expand only 5·9 times, while the 75-lb. charge in the 15-inch gun can expand 16 times. The 700-lb. shot burdens the pressure with a load of 6·2 lbs. per inch, the 1,000 lb. shot with only 5·66 lbs.; the former also is set in motion by a stroke of 135 inches while the larger projectile is accelerated throughout the space of 180 inches.

Another thing has also to be considered. The projectiles for the wrought-iron gun allow a considerable escape of the gas to take place through the windage. The escape, of course, is greater when the pressure is higher, and when the load being heavier, there is more time for the gas to pass.[1] This waste of power through windage may be scarcely worth consideration in small guns; but in large ones it becomes a serious item. The projectiles proposed to be used for the 15-inch rifled gun would prevent a large proportion of this escape; they are of the expanding nature, like those fired from the Author's rifled cast-iron guns, and similar to those used for the American 12-inch 620-pounder.[2] In Figs. D and E, Plate 24, expanding shot and shell of 1,000 lbs. and 1,200 lbs. weight are shown, such as would be suitable for 15-inch rifled guns. Their form or general proportions cannot be objected to.

But it will be asked, what penetration would these 15-inch projectiles effect, and whether the gain of power secured by the larger calibre is equal to the greater work involved in making larger holes? The power of projectiles to punch their way through iron plates is determined by comparing the "energy" with the circumference of the projectile. In all the recent official tables the "*vis viva*, or energy per inch of shot's circumference" is given as expressing the true plate-punching power.

Now the 700-lb. 12-inch shot, fired from the 35-ton rifled gun with 110 lbs. of powder, giving a velocity of 1,272 feet, has rather more penetrating force than the 1,000-lb. 15-inch shot would have if delivered with a velocity of only 1,140 feet, in the proportion of 209 foot-tons per inch in the former to 192 foot-tons per inch in the latter, near the muzzle. But it is doubtful if this superiority would be maintained when striking at a distance of 2,000 or 3,000 yards. The higher velocity of the 12-inch shot entails greater resistance in passing through the air than the other encounters in moving more slowly. The 15-inch 1,000-lb. shot, being nearly the same weight in proportion to its area of section

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[1] If the 15-inch gun were rifled like the Woolwich guns for studded shot, about 15 to 20 per cent. more powder would be required than for expanding projectiles.

[2] *Vide* Appendix, Note 5. Expanding Projectiles for Ordnance.

(5·66 lbs.) as the 11-inch 535-lb. shot of the British service (5·7 lbs.) would retain its force as well during flight; and starting with a velocity of 1,140 feet, it would only lose 140 feet velocity in 2,000 yards, like the 11-inch shot when travelling at the same speed. At this range, therefore, it would have a remaining energy of 6,943-foot tons and a punching power of 148 foot-tons per inch of circumference. That of the 11-inch 535-pounder at the same distance is 132 foot-tons, and that of the 12-inch 600-pounder 131 foot-tons, according to the official Tables of remaining velocities.[1] This 192 foot-tons at starting, or 148 foot-tons at 2,000 yards, would surely be enough when combined with such an enormous racking effect. There is certainly a limit to the thickness of armour which ships can float with. Experiments at Shoeburyness have proved that a force of 112·1 foot-tons per inch, striking fair, will go through the best iron plates 9 inches thick. Plates of 8 inches will not resist 88·5 foot-tons per inch.

The strongest target for sea-going ships yet tried was that representing the 'Hercules.' It had 9-inch plates, with 12 inches of wood backing. The 10-inch Woolwich gun succeeded in piercing this armour; and the punching power of its shot, as it leaves the gun, with the full battering charge, is 165·6 foot-tons per inch of circumference. The 1,000-lb. 15-inch shot, with 1,140 feet velocity, represents far more than this, viz., 192 foot-tons per inch. This might be done with shells containing heavy bursting charges. Such a force would certainly carry the projectile through both the plate and its backing, making a hole 15 inches in diameter as it went in, but it would be difficult to say how large as it came out, especially if it were a shell with about 20 lbs. of powder exploding *en passant*.

It is, however, to be observed that the small charge of 75 lbs. has been proposed merely on the supposition that, in producing such a vast force as 9,023 foot-tons, the recoil of the 35-ton gun would be as much as could conveniently be controlled. The strength of the gun, as proposed to be made, does not present any obstacle to the use of much larger charges. If heavier charges were employed, and the recoil were found excessive, a few more tons of cast iron might be added, not for strength, but merely as a make-weight. It might then be fired with 88 or 90 lbs. of powder and 1,200-lb. projectiles. This, or a pound or two more powder,

[1] *Vide* "A Text Book of the Construction and Manufacture of the Rifled Ordnance in the British Service." By Capt. F. S. Stoney, R.A., and Lieut. C. Jones, R.A., London, 1872, p. 194.

would certainly give a velocity of 1,130 feet per second, which would cover 1,000 yards with an elevation of $2\frac{1}{2}°$, 2,000 yards with $4\frac{1}{2}°$, and 3,000 yards with about $7\frac{1}{4}°$. The 1,200-lb. projectiles would be of the ordinary proportions; and their resistance per inch of area (6·79 lbs.) would be about the same as that of the 700-lb. shot (6·76 lbs.) fired from the $11\frac{1}{2}$-inch "Woolwich Infant" before it was improved by having its bore enlarged. This resistance of the 1,200-lb. shot per inch of section is less than that of the 400-lb. 8-inch cylinders, ten of which were fired, with the old violent and destructive L. G. powder, out of the Author's rifled 68-pounder cast-iron gun unstrengthened. The resistance of those cylinders was 8 lbs. per inch of area, or more than 18 per cent. in excess of that of the 1,200-lb. 15-inch projectiles.

Table V. will be found to afford a general comparison of the power of all the principal guns now in the services of the United States and of Great Britain, as regards striking force, and penetration or punching energy. The estimated power of the proposed 15-inch gun is also set down; and it will be seen that it would be a more efficient weapon than either of the others. This gun might be made in less time, and at little more cost, than the 8-inch Woolwich guns;[1] and, as it would do its work by mild means, it would be likely to last longer.

In a large-bore rifled gun like the proposed 15-inch 1,000-pounder or 1,200-pounder, to be fired with charges of powder from 75 lbs. to 88 lbs., there is no difficulty in providing strength, nor need there be any doubt, as in the case of the 35-ton wrought-iron rifled gun, whether the charge will be burned, or even ignited; for it is true that when the 120-lbs. charge was fired for which this wrought-iron gun was designed, much of the powder was blown out of the muzzle, unburned. It is not difficult to form a fair approximate estimate of the maximum strain that would be caused by, say, the larger of the two charges, viz., 88 lbs. of pebble powder and 1,200 lbs. projectiles. The 15-inch and 20-inch American smooth-bored guns, when fired with 100 lbs. and 200 lbs. of powder, resembling English "pebble," are said to be subjected to about 12 tons per inch. The measurements taken in the United States indicate this; and it is certain that if the pressure were much more, such guns could not stand as well as they have been found to do. But English official measurements taken with superior instruments, and in rifled guns, may be referred to. In

[1] The present cost of the 8-inch guns is stated in a Parliamentary Return, No. 177, 24 April, 1871. Army Rifled Guns, p. 15, to be from £600 to £800 each.

TABLE V.

COMPARISON of the POWER of the principal GUNS in the AMERICAN and in the BRITISH SERVICES.

	Weight of Gun.	Length of Bore.	Charge.		Initial Velocity.	Vis Viva or Energy.	Punching Power. Energy per Inch of Shot's circumference.
			Powder.	Shot.			
	tons.	inches.	lbs.	lbs.	ft. per sec.	foot-tons.	foot-tons.
AMERICAN.							
Cast-Iron.							
20-inch Smooth .	50	210	200	1,080	1,520	17,323	279·0
15 do. do. .	20	163	100	480	1,538	7,864	168·9
11 do. do. .	7	132	30	180	1,430	2,555	75·0
10 do. do. .	5	119	20	130	..	..	..
9 do. do. .	4	107	15	93	..	..	..
12 do. Rifled .	21	163	70	620	1,183	6,020	162·8
32-pr. (Old) do.[1] .	51-cwt	113	6	64	1,210	651	34·3
BRITISH.							
Wrought-Iron.							
12-inch Rifled .	35	163	110	700	1,272	7,863	209·0
12 do. do. . .	25	145	85	600	1,300	7,030	188·0
11 do. do. . .	25	145	85	535	1,315	6,415	187·0
10 do. do. . .	18	145	70	400	1,364	5,160	165·6
9 do. do. . .	12	125	50	250	1,420	3,496	124·7
8 do. do. . .	9	118	35	180	1,413	2,492	100·2
7 do. do. . .	6½	126	30	115	1,525	1,855	85·3
6·4 (Palliser) do.	71-cwt.	103	8	64	1,170	608	32·0
PROPOSED.							
15-inch Rifled .	35 to 40	192	75	1,000	1,140	9,023	192·0
Do. do. . .	35 to 40	192	88	1,200	1,130[2]	10,638	226·4

[1] Converted without being strengthened.

[2] A projectile of this weight in proportion to its area (6·79 lbs.), starting with a velocity of 1,130 feet, cannot lose more than 116 feet per second in a range of 2,000 yards. At the same range the 600-lb. 12-inch shot, starting with 1,300 feet per second, loses 215 feet velocity.—*Vide* "Text Book of Rifled Ordnance," p. 194. The 1,200-lb. 15-inch shot at 2,000 yards would have a remaining energy of 8,566 foot-tons, or 182 foot-tons per inch of circumference (punching power). The 700-lb. 12-inch shot fired from the Woolwich gun, with the extreme charge of 120 lbs. powder, which gives an initial velocity of 1,315 feet, must lose 205 feet in 2,000 yards, leaving an energy of only 5,976 foot-tons, or 161 foot-tons per inch of circumference; or nearly 40 per cent. less actual force, and 10 per cent. less punching power than the 1,200-lb. 15-inch shot.

Table II. (p. 194), it will be seen that, when the 700-pounder "Woolwich Infant" was tried with a bore of 11½ inches, and 75 lbs. of powder, in a cartridge nearly 20½ inches long, a pressure of 17 tons per inch was produced. It is also observable, in the

same Table, that from a less charge (70 lbs.), in a cartridge more than 25 inches long, fired in the 10-inch gun, with shot of only 400 lbs., the pressure was from 2 to 3 tons more. By boring out the 35-ton gun to a larger calibre the strain caused by similar charges of the same powder proved in all the trials to be greatly lessened. This shows how much the question of calibre affects that of pressure; and, as a consequence, that of the required strength inthe gun to control the pressure.

If the conditions under which the 75-lb. charge was fired in the 11½-inch bore are compared with those of the 88-lb. charge proposed for the 15-inch 1,200-pounder in relation to area, the following figures present themselves:

	Per Inch of Area.	Pressure.
11½-inch Rifled Gun:— Area of bore, 103·8 inches. Powder, 75 lbs. Shot, 700 lbs. Cartridge, 20·4 inches long	= Powder, ·72 lb., Shot, 6·74 lbs,	gives 17 tons.
15-inch Rifled Gun:— Area of bore, 176·7 inches. Powder, 88 lbs. Shot, 1,200 lbs. Cartridge, 14 inches long	= Powder, ·498 lb., Shot, 6·79 lbs.,	gives ?

From this view of the conditions, taken in conjunction with the other facts noticed, it is not probable that this 15-inch rifled gun would be subjected to any greater strain than 13 or 14 tons per inch. On the other hand there are good grounds for the conviction, that this would yield an available projectile force superior to anything yet produced in this country, whether for "racking" or punching, even when gunpowder was worked to a pressure of upwards of 60 tons per inch. It follows, then, that it would be absurd to employ 35 or 40 tons of expensive wrought iron in making such a weapon. In Table III. (p. 196) it may be seen that a thickness of 13½ inches of wrought iron can safely control the pressure of nearly 30 tons per inch in the 8-inch Woolwich guns. Still, 30 or 40 tons of metal at least must exist in the 15-inch gun, or its recoil would be too violent.

The method of construction which the Author proposes for consideration remains to be explained. The object is to provide strength in full and ample quantity where strength is needed, but for mere ballast to use a cheap material. It is, however, to be understood, that whatever novelties may be found in the mode of construction proposed, they are to be considered on their merits or demerits, but are not to be mixed up with the general

design of the weapon, which embraces the questions of calibre, charge, and projectile.

The body of the gun, A A, Fig. 5, is made of cast iron. B is a breech piece of superior metal, either wrought iron, mild steel, bronze, or any other suitable material. It is secured in the cast-iron body by a long screw thread on its circumference. The thickness of the breech piece may, of course, be less or more than is shown; probably the substance represented is beyond what would be needed. C is a steel tube within the breech piece, which is shrunk upon it in the usual way; this is provided against the local wear which occurs at the seat of the shot. The tube may be carried to the muzzle in one piece, or it may go no further than is represented, and be there connected with a wrought-iron tube (*d*) for the rest of the bore. Wrought iron would be likely to do as well as steel for this forward tube, as it would not be subjected to the wear which takes place near the seat of the shot. The butt joint of the tubes, made air-tight, would, it is believed, be found unobjectionable at this part of the gun, where the gas will have expanded so largely, and its tension become so reduced. This arrangement would admit of the tube being easily repaired, or renewed, if injured by the premature explosion of a shell, or on becoming, in course of time, worn. The forward tube for the chase may taper towards the muzzle, and be secured by screwing into the wrought-iron breech piece; the direction of the thread being the reverse of that of the rifling, to prevent the shot from turning the tube in following the rifling. Although the cast-iron body, or outer shell, of the gun might be in one piece, if desirable, it is shown in two pieces, jointed, like a poacher's fowling-piece, by a considerable length of screw at the shoulder in front of the trunnions. This novelty in the construction of a large cannon is not likely to pass without challenge; still, after careful consideration, the Author does not hesitate to propose it as a feasible contrivance, calculated to be of great utility, for several reasons. All that the thread of the screw would have to do is to hold the chase as the gun recoils; a far less severe trial than falls on the screw of the Armstrong 100-pounder breech-loader, where the thread has to sustain the whole shock of the explosion while the projectile is being started and compressed into the bore. Large cast-iron guns have been tried, in which the end of the bore was closed by a screwed plug, and they have been fired to the bursting point without the thread becoming injured.

For such guns of great length it would be easier to mould and cast the outer portions in two pieces than in one; there would be

less metal to pour at a time; and compared with such castings as the American guns, the work would be simple. The hollow cylinders being open at both ends, more facilities are afforded in providing for the escape of the air; and the evils attendant on unequal contractions of the iron in cooling would be easily avoided, and more soundness of metal secured. But there would be a greater advantage than this. Guns of excessive weight are difficult to move, and this may often prevent their being used where they would be of great use, as in sieges. The Germans could bring no guns to bear on Paris, or any other beleaguered place, heavier than rifled 60-pounders. There are many commanding points on elevated positions where ordnance of great weight could not be taken without extreme difficulty, if at all. But when constructed in the manner proposed, they might be transported in parts, and, without the aid of machinery, be put together on the spot they are designed to occupy. At first sight it may appear a bold proposition to make large guns to screw together in this way; but in view of the manifest benefits it might afford, the Author submits that the plan is worth consideration, and should not be set aside at once as impracticable merely from preconceived ideas.

It remains to estimate what would be the cost of manufacturing the proposed 35-ton 15-inch rifled guns compared with others.

When, some time ago, Sir Joseph Whitworth and Co. were asked for an estimate for a 35-ton gun, of their particular kind of iron, they pointed out in their letter to the authorities, dated 13th Jan. 1870,[1] that £4,000 each had been paid by the War Department for 13-inch guns of 23 tons, and they proposed to charge the same price per ton. This would have made the cost of a 35-ton Whitworth gun £6,100. Sir W. Armstrong and Co. were also invited to send in an estimate, and the Elswick tender was £3,500, as stated in a letter to the War Office of 16th February, 1870. The estimate from the Royal Gun Factories, dated 28th January, 1870, for the gun which was eventually made, was £2,472, but this was, no doubt, exceeded. The probability is that, when everything has been included, the sum actually paid for the "Woolwich Infant" will be found to approach £3,000.

In the proposed 15-inch rifled gun there may be about 27 tons of cast iron and 8 tons of superior metal. The usual price for cast-iron heavy ordnance was £20 per ton, delivered in a finished state, bored and turned. The castings for the proposed guns ought to

[1] Parl. Ret. Ordnance, 26th May, 1870.—35-Ton Gun Competition.

be considerably cheaper than this; because, being moulded on a core throughout their length, instead of being cast solid, there would be less waste of metal, and also less labour in boring them to the size required, and less risk from unsoundness. For the breech piece, as only moderate charges would be used (causing not much more pressure than cast iron alone would suffice for), it is a question whether Bessemer steel, or some other of the now cheaply produced malleable irons, having great tensile strength, would not be just as good as the costly material at present employed at Woolwich. It might be obtained for about half the price. But for the purpose of an estimate, the materials may be reckoned at the extreme price which, in their finished state, they now cost—the 27 tons of cast iron at £20, and the 8 tons of superior metal at, say, £45 per ton. This would bring up the cost of the 15-inch 1,200-pounder rifled gun to £900, which is one-seventh of the Whitworth estimate, one-fourth of the estimate from Elswick, and certainly less than a third of what the 35-ton gun actually cost at the Royal Gun Factories.

Most likely, however, such weapons might be made in quantities for between £800 to £850 each; and they would possess a margin of strength three or four times greater than they would ever be required to put forth. The great strain would fall on about the same thickness of superior metal as there is in the 8-inch Woolwich guns, which are known to be capable of resisting more than 30 tons per inch; and this is supported by a wall of 8 or 9 inches of cast iron.[1] This amount of lateral strength is continued round the bore throughout so much of its length as would afford the charge space to expand about six times, and beyond this the gun is not subjected to greater pressure than is expended on the air at the muzzle of the Woolwich guns—a pressure of 150 atmospheres, or more, entirely thrown away. This is shown by the chronoscope experiment of the Committee on Explosives, Table I., p. 192.

In conclusion, the Author desires to express his obligations for being allowed to draw so largely as he has done on the patience of the members of this Institution. His object has been to submit the results of much careful thought, combined with some practical

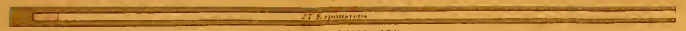
[1] In the Palliser gun the longitudinal strain falls on the cast iron at the end of the tubes, the latter giving very little support. In Mr. Parsons' arrangement the steel tubes do not afford, in the thickness of metal at the sides, the same longitudinal strength as the proposed substantial breech piece, which, so far as it extends, is itself a wrought-iron or steel gun of ample strength for the work.

experience of a subject, which is one not of mere commercial interest, but of national concern. Should what has been urged contain truth, it will be turned to account elsewhere, if not in this country. No men can be better fitted to form, and to express, an authoritative opinion on such a matter, than the Engineers of the greatest Engineering nation in the world. And although, from peculiar circumstances, the British Government may have become committed to a system of gun construction which is identified as an official child, named after the place of its nativity, and doubtless the object of special regard, a fair criticism of that system, as a thing of science, by independent Engineers, will scarcely be disregarded by those who are responsible to the country for the judicious expenditure of the public money.

The communication is accompanied by a series of diagrams, from which Plate 24 has been compiled.

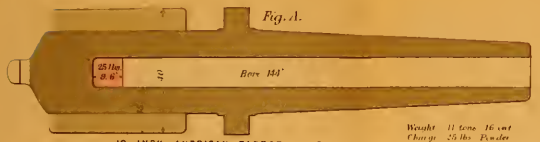
CONSTRUCTION OF HEAVY ARTILLERY.

Fig. 1.



WHITWORTH SMALL ARM
Scale 2 inches = 1 Foot

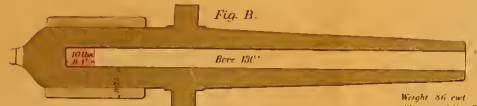
Fig. A.



10 INCH AMERICAN PARROT 250 POUNDER.

Weight 11 tons 16 cwt
Charge 25 lbs Powder
250 " Shot (Expanding)

Fig. B.



6 4 INCH PARROT 100 POUNDER.

RANGE
at 5° 2200 yards
10° 3800 "
15° 4800 "
35° 8845 (5 Miles 45 yards)

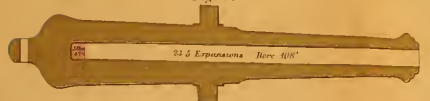
Weight 86 cwt Calibre 6·4 inches
Charge 10 lbs Powder
" 100 " Shot. (Expanding)

Fig. C.

PALLISER CONVERTED 8 INCH OF 11 CWT.

Calibre 6·3 inches
Charge 8 lbs Powder (R L C)
6·1 " Shot (Studs)

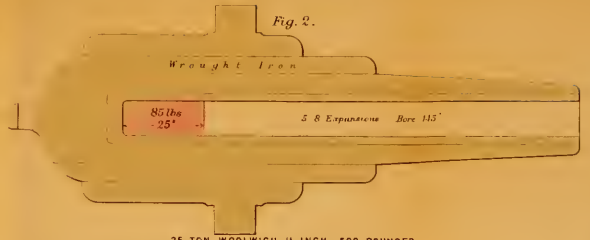
Fig. 4.



RIFLED 32 POUNDER 56 CWT. (BRITTEN)

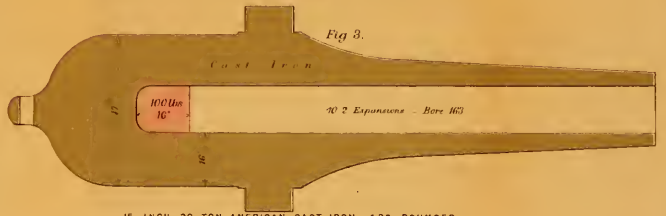
Scale ½ of an Inch = 1 Foot.

Fig. 2.



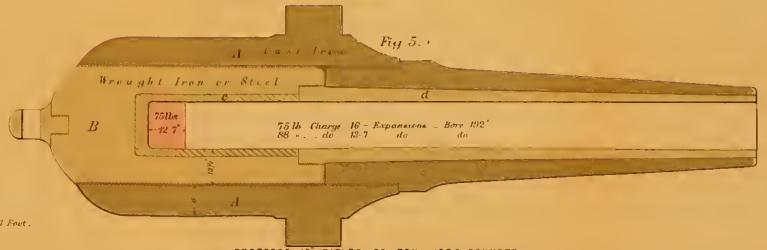
25 TON WOOLWICH 11 INCH. 500 POUNDER.

Fig 3.



15 INCH 20 TON AMERICAN CAST IRON, 480 POUNDER

Fig 5.

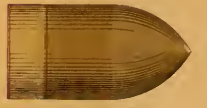


PROPOSED 15" RIFLED 35 TON. 1200 POUNDER

Figs. D.

ELEVATION, 15 Inch 1000 lb. Shot

SECTION, 15 Inch 1000 lb. Shell



ELEVATION, 15 Inch 1200 lb Shot

SECTION, 15 Inch 1200 lb Shell

Enlarged Section shewing thickness of Soft metal and position of Shot piece Section at A Fig E

Fig. E

PLAN of Brass Shoe

BASHLEY BRITTEN, DELT

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REED BROTHERS CASTLE STREET

APPENDIX.

Note 1.—The Official Report on Mr. Bashley Britten's Rifled Cast-iron Service Guns.

Although this invention was under official consideration for nine years, during which it was extensively tried, the restrictions imposed upon its proposer did not enable him to work out all its details fully, so as to demonstrate the ultimate capabilities of the scheme; still enough was done to cause the late Ordnance Select Committee to report upon it favourably. Several other plans for rifling the old guns were proposed after this was submitted in 1854-5, and, during the period from 1859 to 1862, there was a competitive trial of all of them which were considered to be at all feasible. This trial formed the subject of a Report to the War Office,[1] where it was printed in 1863.

The following extracts will show what was allowed to have been established by the experiments:

Extract No. 1 *from Report* (p. 14).

"The Committee conceive that the invitation to certain gentlemen to compete against one another, to produce the best method of rifling cast-iron guns, renders it necessary that they should specify who has in their opinion been most successful, whether his plan is or is not carried out. They have no hesitation in awarding the first place to Mr. Bashley Britten, on the ground of the comparatively little strain on the gun, caused by projectiles on his system, with the moderate charge he advocates, as shown by the great endurance of a large number of guns rifled for him, and by the high initial velocity attained. In point of accuracy, this system appears to be on the whole equal to that of any other of the competitors."

Extract No. 2 *from Report* (p. 16).

"It will be observed, however, that Mr. Britten's results are obtained at a cost of much less strain on the gun than those of either of the other plans, and the Committee believe that if circumstances of urgency warrant the rifling of cast-iron, it may be done on this system with less risk than on any other they are at present acquainted with. They trust that no such urgency will arise, and that so precarious a material will not come into use for rifled artillery.

"Such guns would, however, if made, be perhaps capable of firing round shot, common shell, shrapnell shell, grape or case shot, with a reduction of the present service charge (the reduction of the 32-pounder charge from 10 lbs. to 8 lbs. only reduces the velocity from 1,690 to 1,619 feet); and apparently with little or no loss of accuracy. They would fire an elongated common shell, containing three times the bursting charge of the round shell, and weighing twice as much, with half the service-charge, or perhaps less; but attaining ranges exceeding those of the

1 "Report of Ordnance Select Committee on Competitive Rifled Cast-iron Guns." Printed at the War Office (Report, No. 2,685, 6th February, 1863.)

service round shot, and possessing much greater precision. For those artillery services in which low charges are necessarily employed, such as enfilading short fronts, dismounting ordnance behind traverses, or breaching sunken defences,—they would probably equal wrought-iron ordnance."

Extract No. 3 *from Report* (p. 14).

Forty rounds of solid round shot were fired with full service charges of 10 lbs. from a smooth bored 32-pounder, and a similar number from a shallow-grooved rifled 32-pounder (Britten's) for comparison. On this practice the Committee remark: "The result is decidedly in favour of the rifled gun. This is more than could be generally expected, but it makes it probable that little or no disadvantage would accrue from the grooving."

Extract No. 4 *from Report* (p. 4).

"The Committee have ascertained that in point of expense there is very little difference between any of these systems. They could any of them be applied to smooth-bored guns on a large scale, at a cost of not more than 10*s.* per gun for rifling, by extending the machinery in the Royal Gun Factories. It is stated by Mr. Anderson that the system of Mr. Bashley Britten would be the least expensive." . . . . "But they would all range between 7*s.* 6*d.* to 10*s.* per gun."

This Report was adopted by the War Office, and in 1863 it was stated in the House of Commons by Sir G. Cornewall Lewis, then Secretary of State for War, that "if the Government were to give effect to the principle of rifling the cast-iron guns, the plans of Mr. Bashley Britten would be preferred."

The Committee in their Report speak of the "low charges" adopted by the Author as rather an objection to his scheme, apparently forgetful of its not being just to measure the power of a gun by what is put into it, but rather by what comes out of it. The low charge was a distinct feature of the invention. In a previous Report to the War Office, dated June, 1861, the Committee instituted a comparison between these rifled 32-pounders and the 40-pounder Armstrongs, then being largely made. They stated: "a smooth-bored 32-pounder gun of cast iron costs, by contract, £58, rifling will add less than £1 to this amount. An Armstrong 40-pounder, which may be treated as the rifled equivalent of the 32-pounder, costs at present £360." Now the charge adopted for this 40-pounder was 5 lbs., the same as the Author used for his 32-pounder, which, as a rifled gun, fired projectiles of 50 lbs. The 50-lb. shell left the 32-pounder with a higher velocity than the 40-lb. shot from the breechloader—the former being 1,209 feet per second, the latter only 1,164 feet. Every pound of powder in the Author's gun yielded 102·3 foot-tons of projectile energy; while the other gun produced but 78·2 foot-tons. Up to about 5° elevation the trajectory of the 32-pounder was as low as that of the breechloader, the range being equal; and beyond any ordinary fighting distance, say up to 3,500 yards (which is further than can be seen to aim), the rifled service gun was a more powerful weapon. One of the 32-pounders was tried for endurance up to 2,000 rounds, and it is still serviceable.

If the two guns, firing the same charge of powder, are compared in respect to the punishment they would have inflicted by 2,000 shots striking an object at a thousand yards (probably the most useful range for any artillery), the cheap 32-pounder would have delivered blows having an aggregate of 758,000 foot-tons of energy; while the costly 40-pounder would have delivered only 534,000 foot-tons, or nearly one-third less. These figures are deduced from the mean velocity at this range ascertained from the observed time of flight.

Note 2.—Large Parrott Rifled Guns.

The 100-pounder Parrott gun was just about the same weight as the 100-pounder Armstrong; but the former was 40 inches longer in the bore. At 5° elevation it had about 250 yards greater range, and at 10° nearly 350 yards the advantage over the English breech-loader. At 35° the Parrott 100-pounder gave a mean range of 8,845 yards, or 5 miles and 45 yards. The 200-pounder 8-inch Parrott gun was 10 inches longer in the bore than the 200-pounder Woolwich gun of the same calibre; but it weighed 7¼ tons, while the English gun weighs 9 tons. The 10-inch 250-pounder Parrott was 18 inches longer than the English 9-inch 250-pounder; and yet it weighed about a ton less. They were adopted during the exigencies of a deadly struggle; were made in haste, and used in service before the iron had proper time to anneal itself; and the charges employed were far beyond their powers. That so much was really done with them is strong evidence in favour of what the material might do if used with proper judgment. The records of endurance of the large Parrott guns are not complete; but it appears that, of the 100-pounders which failed, or became disabled during the war, six had fired over 300 and under 500 rounds each; four from 500 to 1,000 ounds; two 1,100 rounds; and three others, 1,225, 1,480 and 1,590 respectively. Of the 150-pounders and 200-pounders, five failed between the 200th and 300th round; two at the 420th; three from the 500th to 600th; one after the 1,063rd; and another at the 1,457th round. Some of them burst explosively, but few compared with those which became unserviceable and were discarded, from cracks showing themselves about the breech. General Gillmore, who commanded the army at the siege of Charleston, states that twenty-three of his Parrott guns failed, but not one life was lost through their failure.—(Report of Joint Committee on "Ordnance," U. S., 1869, p. 43.)

Note 3.—Comparison between the 12-inch and 11-inch 25-ton Woolwich Guns.

The first 25-ton Woolwich guns were made with a calibre of 12 inches; the more recent ones have bores of only 11 inches. It is said they are improved by this reduction of calibre; because, although the 12-inch 600-pounder gun with the same charge of powder delivers its shot with much more energy, this energy has to be expended in overcoming the resistance due to its larger area of section in penetrating the atmosphere, and its greater circumference in punching holes through iron plates. The 11-inch gun with its 535-lb. projectile, at 1,000 yards range, is found capable of effecting greater penetration than the 12-inch 600-pounder with the same charge. But does not this depend upon the shot used? The 11-inch shot of 535 lbs. is heavier than the 12-inch shot of 600 lbs. in proportion to its sectional area, and therefore it is possessed of more carrying or conservative power. To render the conditions equal the 12-inch service shot should weigh about 645 lbs. instead of only 600 lbs. This would give the same proportion to area. If shot of this weight were tried, there is little doubt which gun would be the better of the two. It is curious that this discrepancy in the weight of the projectiles does not appear to have been noticed as accounting for the different results.

Note 4.—Rodman Hollow Cast Guns.

It was long supposed that the plan adopted in the United States, of casting large guns hollow and cooling them from the inside with water, so as to bring the metal into what was called a state of 'initial tension,' produced strength and enduring qualities superior to solid cast guns. Practically, however, it has been found

that there were many objections to this method of casting, and that, after a time, the metal naturally arranged itself into the normal condition of other iron. Great uncertainties and irregularities were produced by internal cooling. No less than ten instances are recorded of these hollow cast large guns cracking or bursting open, either before being taken out of the pit, or when put into the lathe to be turned. One 15-inch gun, in bursting in the lathe, produced a report said to be as loud as that of a 6-pounder gun when fired. There is no doubt that several of the failures which occurred in the proof of these castings were due to this. It has therefore been reported that "the principle of initial tension, which is the basis of the Rodman system, appears to be of doubtful utility, as applied by General Rodman, especially for rifled guns. This tension, it is admitted, gradually disappears from the gun with age, and in time is entirely lost."—(Report of Joint Committee on "Ordnance" in the U. S. Senate, 1869, page 5.)

Note 5.—Expanding Projectiles for Ordnance.

There is no reason why this mode of obtaining the rifle action should not be quite as successful as when studs or buttons are used for the purpose. All the difficulty which once existed of getting a perfect attachment of the soft metal to the iron is entirely conquered, and projectiles of this character have several decided advantages over the others. Being plain cylinders, they can be put into the gun without any of that particular adjustment into the grooves which the studded shot require. They would also pack or pile closer, and probably be less costly; and the zone of soft metal being protected at both extremities, as may be seen by Figs. D and E, Plate 24, the projectiles would scarcely be so liable to injury as those with studs, which are required to fit well in the grooves. If the bronze studs become bruised they will not go freely into the rifling, and frequent instances occur of the studs overriding the rifling, and so causing excessive strain on the gun. But a far more important advantage in the expanding projectiles lies in there being no holes to be drilled as in the others. These holes materially weaken the shells, and render them liable to break up in the bore and injure the rifling. At present the premature explosion of loaded shells in the gun from this cause is very common, and lower charges have to be adopted for explosive projectiles. The expanding projectiles also, by preventing escape of gas, enable equal velocities to be obtained with from 15 to 20 per cent. less powder. This was proved by the experiments of the late Ordnance Select Committee.

Note 6.—The Conversion of Cast-iron Ordnance into Rifled Guns.

At the time the Author's plan for rifling the old guns was under consideration and trial (1854–1863), there were no instruments for measuring pressures in ordnance, and there was no powder in use except the L.G., a kind which was more destructively violent than the present R.L.G. Notwithstanding the Committee, in their final Report, confessed their inability, in the absence of failure, to give satisfactory reasons for rejecting the plan, it was ordered to stand over, without being rejected, and was reserved as a useful invention which, at any time, might be employed in case of need.

When the chronoscope revealed the true character of the old powder, and a better kind was introduced, the Author pointed out to the War Department that, as his rifled cast-iron guns had never failed in any of the experiments with the violent explosive, there could be no risk with that which reduced the strain one-half. He also pointed out that in other countries cast-iron rifled

guns were being used, and were found perfectly satisfactory; that not only in America, but also in Belgium, and recently at the siege of Paris, cheap guns of the kind, with suitable powder, were found to do their work as well as any of the same weight. But the plan of strengthening the guns laterally with inner tubes having been adopted, the Author's representations were fruitless. According to the Report of the Committee who recommended the Palliser mode of conversion in 1868, there are from 5,000 to 6,000 32-pounders and 68-pounders ready to be rifled; and on this plan it will require an outlay of nearly a million of money. All the rest of the cast-iron guns, including 18-pounders and 24-pounders, which, for a few shillings each, might be turned into thoroughly efficient rifled 36-pounders and 50-pounders, are, according to present plans, to be thrown into the melting-pot, or sold for old iron. A short time since (Oct., 1871,) a large number of them were publicly advertised for sale. They cost, all round, about £22 per ton, and they were to be sold for about £4. They are as good as, or better than, when first made; not one in every twenty has fired 50 rounds. Tens of thousands of them exist, and will have to be replaced, for guns of moderate size are as requisite as monster ordnance. At this moment (1872), with few exceptions, British fortresses have scarcely anything else. There are not enough of the approved new guns to thoroughly arm the navy and the new fortifications building to secure such positions in the "first line of defence" as the Thames, Portsmouth, and Plymouth. What it will cost to replace them, and when it will be done, it is not easy to conjecture. Nor would it be necessary if powder were allowed to be used such as is employed in other countries for cast-iron rifled guns.

[Capt. Maitland

Captain Maitland, R.A., said, the few remarks he had to offer might seem in some respects at variance with the conclusions deduced by the Author of the Paper; still, from his position in the Royal Gun Factories, he had become aware of some facts which bore more or less on the system of gun-making advocated by Mr. Britten, and which he thought it right to communicate to the Institution. It was stated in the Paper that service guns of 7-inch calibre and upwards were deficient in endurance; also, that they were unnecessarily strong. Now, with regard to endurance, hitherto not one of the heavy rifled guns made on the present system had ever burst explosively on service. Some had been injured, to the extent of requiring a new inner tube, but that was all. They had not been tried long enough to ascertain an average for the life of a gun; but he would mention a few guns which had fired a great number of rounds.

No. 1, 9-inch, had fired 1,070 rounds, simply requiring to be turned over and revented.

No. 5, 9-inch, had fired 989 rounds, requiring the same repair.

No. 216, 9-inch, had fired 1,107 rounds; same repair.

No. 339, 9-inch, had fired 1,049 rounds; same repair. The tube of this gun was now cracked, and when the gun was issued for service it would require a new tube.

No. 2, 7-inch, fired 1,387 rounds; it then received a new tube, and had now fired 400 rounds more, being perfectly serviceable still.

No. 208, 8-inch smooth-bore, had fired 1,332 rounds. This gun was used for testing powder, and consequently had to support a great variety of strain. Its bore was originally 7 inches, and when it was made an 8-inch gun it received a new tube. This was the gun from whose practice the Tables in the Paper were constructed.

There was now in use at Shoeburyness a 7-inch Armstrong breech-loader gun, which had fired over 2,000 rounds, and there were several which had fired over 1,000 rounds. These guns never burst on service, and this was the most important consideration of all. As to the service guns being unnecessarily strong, the Author stated that, having been strong enough to resist R. L. G. powder, the guns might advantageously be made lighter for use with pebble powder. Now the object kept steadily in view by the authorities was to get the highest possible velocity out of a gun with the heaviest possible projectile, or, in other words, to get through the thickest armour plate at fighting distance. The charge of pebble powder had therefore been raised as much as possible; but, unfortunately, even this powder was not so regular in its action as could be desired, and there was a liability to heavy strains on the

guns at any time. For instance, in proving 35-ton guns a few days ago, filling the cartridges with the same description of powder, he found the pressures with 115 lbs. of powder varied from $22\frac{1}{2}$ to $32\frac{1}{4}$ tons on the square inch at the bottom of the bore; while with another brand of pebble the pressure had been 48 tons. The charge which cracked the tube of the original 35-ton gun was 120 lbs., but the gun had previously withstood a charge of 130 lbs., when its bore was 11 inches. It must be borne in mind that the pebble powder was new; the principle of its manufacture was that, the grains being large, and affording free interstices, they would light rapidly, indeed almost simultaneously, but that each grain would burn slowly, and the gas would therefore be evolved with regularity. The actual composition of pebble powder was the same as that of R. L. G. The grains were fairly regular oblong or square masses, and when they fell together in the cartridge might either leave the desired interstices or might perchance fall evenly together, and fit like bricks in a wall. In the latter case, the mechanical conditions of regular evolution of gas were not fulfilled. Again, supposing this powder to be carried about over the world, many of the large grains would probably be broken up, and fail to afford the desired regularity. When this occurred violent strains would be sure to take place; and it was the undoubted duty of the gunmaker to see that his gun was calculated to resist any strain that could be foreseen.

Foreigners did not always find their guns strong enough. There was occasionally a report of the bursting of one of even Mr. Krupp's steel guns, which cost more than double the price of the British guns. He was quite ready to admit that the 35-ton gun was not perfect in its construction. It was made according to order, 16 feet long and 4 feet 8 inches thick, to fit certain turrets already designed, and had cost £2,400.

The proof of cast-iron smooth-bores at the Arsenal had certainly been comparatively greater than that to which wrought-iron guns had been subjected, but this was because it was necessary to allow a greater margin of strength. A cast-iron gun might burst at any time; it gave no warning, but suddenly flew to pieces, dealing destruction to all around. This might appear a sweeping condemnation, but it was true. It would be just as reasonable to employ cast iron for boilers as for guns.

With regard to the proposal to make the trunnion hoop of cast iron because the employment of pebble powder lessened the strain, he wished to point out that in the 8-inch gun, for instance, the strain on the part of the bore between the trunnions was about

2 tons per square inch greater with pebble powder than with R. L. G. powder. This was apparent from the curves denoting the pressures of the two powders.

Guns were dependent on the explosive. In time of war, R. L. G. powder might be the only powder to hand. Preparation must be made for the roughest usage by sailors at all times, for all risks, and for any deficiency of intelligence on the part of soldiers in the heat of action. Preparation must also be made for heavy shells bursting inside the guns, and there must be no fear of rapid and continuous firing. The bursting of one gun in action between a ship's decks would demoralize the men more than the severest fire of the enemy.

Lieut. C. Jones, R.A., Captain-Instructor Royal Gun Factories, said the reference in the Paper to the Report of the Joint Committee of the Senate and House of Representatives of the United States upon ordnance, in support of the use of cast iron for heavy guns, might lead to the supposition that the Committee had recommended cast iron as a material for rifled ordnance; but he did not read it in that sense. Thus it was stated in the Report:[1]

"Guns cast solid, in the manner practised in the navy under the direction of Rear-Admiral Dahlgren, while exhibiting satisfactory endurance as smooth-bores with small charges and hollow projectiles, have not the requisite strength for rifles of large calibre. This mode of casting seems to be defective in principle, as the tensions inaugurated in cooling have a tendency to aid the powder to rupture the gun."

Again:[2]

"Each system of guns introduced in our service has been subjected in proof to tests supposed to demonstrate beyond question its ability to perform the work required of it, but each has failed when submitted to the real test of service. In the operations upon Morris Island 22 large guns was the greatest number mounted at one time, yet 50 in all burst during the siege, as is shown by the evidence of General Gillmore. In the attack on Fort Fisher all the Parrott guns in the fleet burst, according to the report of Admiral Porter. By the bursting of five of these guns at the first bombardment 45 persons were killed and wounded, while only 11 were killed or wounded by the projectiles from the enemy's guns during the attack. The battle of Fort Fisher was the only occasion during the war when rifled guns of large calibre were fired rapidly and continuously for a great number of rounds."

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[1] *Vide* page 5.

[2] *Vide* page 2.

The Committee further reported:[1]

"The present system has failed to answer the purpose for which it was designed, and the United States is in the position to-day of a nation having a vast coast-line to defend, and a large navy, without a single rifled gun of large calibre, and a corps of ordnance officers who have thus far failed to discover a remedy for the failure of the guns, or to master the rudiments of the science in which they have been trained at the public expense."

He had that day heard from good authority that the Americans considered themselves at the present moment to be utterly "at sea" on the question of guns. They recognised that their large smooth-bore cast-iron guns were practically useless in these days of heavily armour-plated ships, and that it was necessary to replace them with rifled guns. They also admitted that they had not got efficient heavy rifled guns to replace them. What they wanted was a gun like the English 10-inch or 12-inch gun, and another extract would show that the views he had heard expressed were contained in the Report of 1869 before referred to:[2]

"The experience of all nations goes to prove that the most effective way of developing ordnance power is by rifled guns. To return to smooth-bores, throwing huge spherical masses of iron with low velocities, is to disregard all modern progress in the science of gunnery, and to go back to the arms in use two centuries ago."

He drew attention to this because in the Paper there was a comparison between the American smooth-bores and the Woolwich rifled guns disparaging to the latter.

The American 15-inch gun threw a spherical projectile of 450 lbs. weight, and fired 100 lbs. of powder, according to the table. But this was only a fancy charge, the service charge for that gun having formerly been 60 lbs. of mild powder, similar to pebble powder, but the charge had been reduced to 50 lbs. Assuming that gun, however, to be fired with a 100 lb.-charge of powder, it gave the large round shot, made of particularly good cast iron, the high velocity of 1,538 feet per second, and a penetrating power of 168·9 foot-tons per inch of circumference; whereas the British 10-inch 18-ton gun had a penetrating power of 165·6 foot-tons per inch of circumference at the muzzle; so that the American 20-ton smooth-bore gun had at the muzzle between 3 and 4 tons greater punching power than the British 18-ton rifled gun. It was not usual however to fight with the muzzles of the guns close to the

[1] *Vide* page 6.

[2] *Vide* page 6.

enemy's ships, and it was therefore necessary to take into account the resistance of the air as well as that of the ship's side. The resistance of the air to the American spherical shot was quite double that offered to the British 10-inch shot; consequently, even at a range of 1,000 yards the 18-ton 10-inch gun was considerably superior to the American 20-ton 15-inch gun in penetrative power.

In attempts to rifle American guns the 15-inch gun blocks were bored to 12 inches and rifled on three different plans, and all of them failed. The first burst after firing 27 rounds with varying charges, the greatest being 45 lbs.; the second burst at the 30th round of charges up to 55 lbs.; and the third was badly cracked at the 16th round of rather smaller charges.[1] This fully supported the statement that the Americans had not a single rifled gun to replace their smooth-bores. Moreover, cast iron was not to be trusted for the exterior of guns. Though there might be no great strain on the exterior under ordinary circumstances, still there was liability to extraordinary strains, such as the bursting of a shell in a gun, which threw greater strain on the gun than it was designed ordinarily to bear. The bursting of one of the guns between decks would be such a serious affair as scarcely to warrant the use of cast iron on the ground of economy, which was the only argument in its favour, or to lead to the abandonment of coils of wrought iron as in the Armstrong gun,—the safety of the latter system of construction having been clearly proved by experience.

He would now give a description of the apparatus for ascertaining the pressure upon the bore of a gun when fired, which apparatus had been designed by Mr. Edmonds, of the Royal Gun Factories, for the Committee on Explosives, to overcome some of the defects found to exist in the Rodman pressure gauge. Fig. 1 represented a sectional elevation of the 'crusher' gauge. He exhibited two of the gauges, one as fitted to the gun, and the other in the form used in the projectile; also some of the copper cylinders by which the pressure was ascertained. The gun was prepared by boring a number of holes 1 inch in diameter in the required positions, and tapping them with a screw thread. The crusher gauge consisted of a steel plug to fit these holes, and it was hollow from end to end. The lower portion was chambered, and the bottom was closed by a steel nozzle, which screwed from below into the main plug, having a hole through it in which the piston worked. In this chamber was placed a separate piece called an anvil, with

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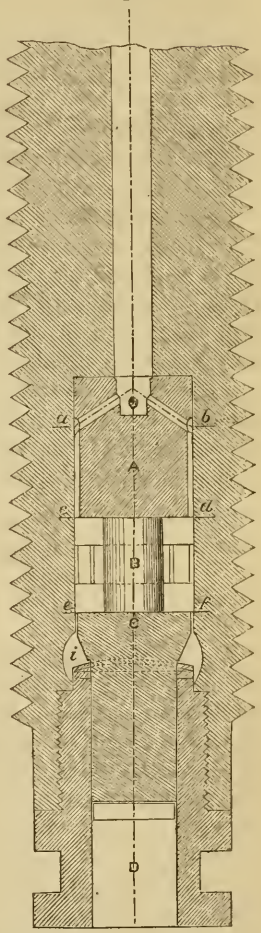
[1] *Vide* Report of Joint Committee on Ordnance, U.S., 1869.

channels through it communicating with the air, to allow of the escape of any gas which might get past the gas-check below the piston. Against this anvil was placed a small cylinder of copper, $\frac{1}{2}$-inch long and $\frac{1}{12}$th of an inch diameter. This was held in the centre of the chamber by a small spring of sufficient strength to prevent its falling from one side to the other, but not sufficient to prevent the copper expanding laterally when the pressure came on it. Against this cylinder of copper the piston rested. Under the piston there was another small spring which prevented undue pressure from being brought to bear on the copper when the nozzle was screwed home, and also prevented the piston falling away by accident from the copper, and so, when the gun was fired, acquiring *vis viva*, and thus giving a blow on the copper. The lower end of the piston was $\frac{1}{6}$th of an inch in area, and was open to the bore of the gun, the gas being prevented from getting past it by a small gas-check. When the gun was fired, the gas, acting upon the piston, forced it up, and crushed the copper to a certain extent; the amount of crushing was a measure of the pressure at that point. To ascertain this pressure coppers were previously crushed in the ordinary compound lever machine used for testing materials in the Royal Gun Factories. A number having been crushed with different weights, the mean compression with each weight was taken, and a curve was drawn. The amount of pressure represented by a certain compression of the copper was thus shown. To ensure that the copper was uniform in quality, and that no error was caused by variation in its density, a number of these crushers, which had been in a gun when fired, and had been crushed to unequal amounts by different pressures, were subjected, in the testing-machine, to a uniform pressure of 43 tons per square

Fig. 1.



Sectional Elevation of 'Crusher Gauge.' Full size.

inch; and it was found that they had all been compressed within from ·002 to ·003 of an inch of the same amount, showing clearly that the variation due to inequality in the density of the copper was slight. Again, to ascertain the nature of the force acting in a gun, coppers, having been once crushed up in the gun, were placed in it two or three times afterwards; and it was found that they were not practically compressed any farther, the same charge of powder being used. This showed that the force acting upon them partook more of the nature of a pressure than a blow.

From calculations he had made, he had come to the conclusion that the Author was rather sanguine with regard to the velocity of shot claimed for the proposed 15-inch rifled gun. The weight of the proposed shot was 1,200 lbs., charge of powder 85 lbs.; that was about $\frac{1}{14}$th of the weight of the shot; and it was calculated that a velocity of about 1,130 feet per second would be obtained. Judging from results already in service guns, he did not think this velocity would be realized. The service guns, of 9-inch, 10-inch, and 11-inch calibre, fired with nearly the same relative charge, or rather more, viz., $\frac{1}{13}$th the weight of shot, gave the following results:

9-inch gun	. . .	967 feet per second.
10-inch „	. . .	950 „
11-inch „	. . .	920 „

Again, the experiments with the 10-inch gun with increasing weights of shot, referred to in the Paper, showed that the velocity to be obtained from any given gun with a constant charge, and varying weight of projectile, varied nearly as the square root of the weight of the shot. With 70 lbs. charge of powder, and 400 lb.-shot, fired from the 10-inch gun, the velocity was 1,351 feet per second. With the same charge of powder and 1,200 lb.-shot the velocity was 802 feet. Calculated by the square roots of the shot, the velocity would have been 799 feet; but with less difference in weight of shot there was a constant difference of about 25 feet between the actual velocity obtained and that calculated by the square roots. Now, in the trials of the Rodman 15-inch gun with 450 lb.-shot at Shoeburyness, a charge of 83½ lbs. of powder was fired—nearly the charge proposed by the Author; this gave a velocity of about 1,400 feet per second. Calculating by the theory of the square roots of the weight of shot for the proposed 15-inch 1,200-pounder rifled gun, a velocity of only 860 feet could be reckoned on. Allowing for any advantage which length of bore, or other difference, might give in the new 15-inch

gun, an extreme velocity of 1,000 feet per second, might be admitted. Assuming this velocity, a comparison might be made between the proposed 15-inch 35-ton gun and the 35-ton Woolwich gun. The latter was a high-pressure gun, firing a large charge and giving a high velocity; the former a low-pressure gun with a heavy shot, fired at a low velocity. The 35-ton Woolwich gun with a muzzle velocity of 1,300 feet gave a penetrative power at the muzzle of 219 foot-tons per inch of shot's circumference. The proposed 15-inch gun, with an assumed velocity of 1,000 feet gave a penetrative power of only 177 foot-tons per inch of shot's circumference, or an inferiority of 25 per cent. At a range of 1,000 yards the penetrative power of the 35-ton service-gun was 183 foot-tons per inch of shot's circumference, while that of the proposed 15-inch gun at the same range was only 152 foot-tons. It therefore appeared that the service 35-ton gun was superior in safety and power, and was only inferior in that it cost more money. These calculations were made for the service-gun with studded shot. He had, however, allowed 140 feet in the calculated velocity for any difference in the proposed gun. Moreover, it was found that the expanding shot proposed by the Author did not give accurate shooting in the 7-inch gun; much less, therefore, would it do so for a 15-inch gun.

Colonel Owen, R.A., observed that the Paper contained three distinct propositions:

1st. A recommendation of a particular system of rifling for both heavy built-up and cast-iron guns.

2ndly. An endeavour to prove that cast iron was a fit material for rifled ordnance, and that it was important to rifle the smooth-bore cast-iron guns, unstrengthened by outer jacket or inner tube of wrought iron or steel.

3rdly. It was stated that in the service-ordnance, great sacrifices had been made to obtain the strength requisite to resist the explosion of large charges intended to give high velocities to projectiles; but that as these latter were not necessary, there had been a waste of money on the materials for the guns, and of powder in firing them. A section was given of a proposed 15-inch gun, designed to economise both material and powder; the chief features of which were the substitution of a cast-iron for a wrought-iron jacket over the breech, a large calibre, a long bore, and provision for a small charge of powder, so that a great number of expansions of the powder-gas might be obtained in the bore.

Now the Author's system of rifling gave excellent results, both as to shooting and endurance when cast-iron guns were fired with

small charges, about $\frac{1}{10}$th of the weight of the projectile; but it failed in later trials with built-up pieces capable of firing charges of $\frac{1}{8}$th to $\frac{1}{5}$th of the weight of the projectile. In the Report of the Ordnance Select Committee, on the trial of the 7-inch wrought-iron guns rifled on various systems, it was stated: "A very short experience showed that the systems of Messrs. Jeffery and Britten were unsuited for heavy charges, large pieces of lead were blown off the shot, and the shooting was so wild as to throw these systems entirely out of the competition."[1] This being the case, small charges were naturally preferred; but, except in special instances, as in curved or vertical fire, high velocities were most desirable, as they gave longer ranges, more accurate practice, and greater striking power than low velocities, and in some circumstances, such as firing at iron-plated vessels, they were indispensable. The racking method —heavy projectiles at low velocities—adopted from necessity by the Americans, who were suddenly involved in war when unprovided with rifled guns, had been long ago exploded. High velocities were fully appreciated in continental services, and by most eminent ordnance manufacturers or inventors, such as Krupp, Armstrong, Whitworth, Lancaster, Palliser, Scott, and others. In fact, a system which did not allow of the use of large charges would be unsuitable for heavy ordnance intended for naval or coast battery service. If the proposed system of rifling would give satisfactory results as regarded velocity, several minor objections might still be raised. On the other hand, several advantages must be admitted; by the expansion of the soft envelope the projectile was centred, thus preventing wear of bore from irregularity in the motion of the projectile in passing through it, and giving accurate shooting in consequence of the axis of the shot being steady on leaving the gun; and as there could be no rush of gas over the shot, the bore would not suffer from scoring.

Seven years ago he stated at the Royal United Service Institution what he believed was the conclusion then generally arrived at, viz., that "a cast-iron gun strengthened by hoops on the outside will fail when rifled, but by placing wrought iron or steel tubes inside, better results may be expected."[2] He mentioned the bursting of the Parrott guns at Fort Fisher, and the extracts just read from the American Report, added to similar opinions expressed by General Gillmore, founded on the failures of cast-iron rifled

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[1] *Vide* Minutes of Proceedings of Royal Artillery Institution, vol. iv., p. 392.

[2] *Vide* Journal of the Royal United Service Institution, vol. ix. p. 349.

guns at Charleston and elsewhere, would not tend to create a belief in such an uncertain and comparatively weak material.

To have rifled cast-iron smooth-bored guns twelve years ago, taking care to limit the charge to $\frac{1}{10}$th of the weight of the shot, instead of plunging wholesale into a comparatively untried breech-loading system, would, he thought, have been wise as a temporary measure. But now that much stronger guns, capable of firing large charges, could be made, to revert to cast iron would be a retrograde measure. The cast-iron guns need not be wasted, as they could easily be broken up and converted into wrought iron suitable for the outer portions of built-up ordnance. The cost of bringing them from Malta, Gibraltar, or such stations, need not be great, for heavy guns being frequently sent out, the cast-iron smooth-bored guns could be sent back on the return voyage.

The introduction of such inferior rifled cast-iron guns would also involve the manufacture and use of a large amount of ammunition different from any other in the service. On this point, and to show that "scientific artillerymen" were not alone responsible for the large and not well-considered expenditure of money on ordnance of late years, he would quote a few remarks he made at the Royal United Service Institution in 1868: "Every effort should be made to reduce the numbers of different natures of ordnance and projectiles with their accessories, for in a service like ours, scattered all over the world, a complicated *matériel* cannot possibly be understood, or therefore efficiently employed;" and "The complication in our *matériel* is no doubt mainly due to the fact that we have been passing through a transition state; but it must not be forgotten, that just when an able and responsible chief was required, there was no Director-General of Artillery, or other principal officer entrusted with the important charge of *matériel;* that the Superintendent of the Gun Factories was summarily got rid of, and replaced by an inventor and Government contractor (a very able man, I acknowledge, and one to whom we owe much), who was made virtually Director-General of Artillery; and that all the experience of the service was set aside, as if a gun had never been made, or at least fired. The wonder is that our munitions of war are not more complicated, and that we have not sacrificed more millions upon them."[1]

A comparison was made in the Paper to show the small relative strain in a gun rifled on the system proposed by the Author. The 32-pounder was taken, fired as a smooth-bored gun with 10 lbs.

[1] *Vide* Journal of the Royal United Service Institution, vol. xii., p. 102.

of powder and 32 lb. ball, and then as a rifled gun with only 5 lbs. charge and 50 lb. shell, and from the greater *vis viva* of the former projectile at the muzzle, it was argued that the strain could not have been greater in the rifled gun. The strain upon a gun might not, however, be proportional to the *vis viva* at the muzzle, force being wasted, as regarded the *vis viva* of the projectile, in the compression system, and also, but to a less extent, in the expansion system of rifling, in giving the soft coating the form of the bore. The Americans complained of the great strain, even with small charges, produced by the expansion system, and the heavy French rifled guns had studded projectiles giving windage to relieve the strain. Having thus compared strains in a smooth-bored and rifled gun, when fired with different charges and weights of projectile, allusion was made to the 10-inch gun fired both as a smooth-bored and as a rifled gun, when the strain was found to be about the same in both. But the smooth-bored 10-inch gun was fired with a cylinder of equal weight to that fired from the rifled gun, and with the same charge as the latter, which gave no idea as to the comparative strains in smooth-bored and rifled guns, as they were usually fired. Even in this case there was a loss of gas down the grooves after the gun had been rifled.

The objection to the use of cast iron on the exterior of a gun had already been stated, and he thought it would be admitted that the money saved by substituting cast for wrought iron in such a place would hardly compensate for the destruction, panic, and distrust caused by the explosive fracture of one or two such pieces.

Although much had been learnt of late respecting the force of fired gunpowder, there were sometimes high local pressures, which interfered with the uniformity of the experimental results, He could not therefore agree in thinking that "means might be adapted to ends (in constructing ordnance) with as much certainty as in making a steam-engine or any other machine." On the contrary, he believed it would be admitted that strength was the first consideration. He had, however, often regretted that more attention had not been given to such elements as calibre and length of bore, for a given weight of projectile and a definite proportional charge. The heavy guns were no doubt too short, and a reason had been given for their having been made so. He had always been in favour of a large rather than a small calibre, because in the former the gas would have a greater number of expansions for a given length of gun, the powder would be more completely consumed and would burn more regularly. He was surprised to hear that a small calibre was the rule in the service. During the Armstrong and

Whitworth gun trials the Government were blamed for adopting a large calibre. He had shown elsewhere the advantage, as regarded initial velocity, of the large calibres of Britten's and Armstrong's guns, but he also pointed out, what the Author ignored, that the projectile of large diameter would lose its velocity more quickly than that with the small diameter, and that the former would only maintain its superiority up to a certain range. In the comparison between the service 12-inch and the proposed 15-inch projectiles the Author broached the peculiar notion, that the higher velocity of the former was a disadvantage, as it "entails more resistance in passing through the air than the other encounters in moving more slowly." Here also, as in other places, reliance appeared to be placed on "racking effect," which experience had frequently shown to be very inferior to perforation.

As to length of bore, initial velocity would increase with it up to a certain point, viz., when the retarding forces of the friction of the projectile against the bore, and the resistance of the column of air in front of it, were equal to the accelerating force of the gas. But such a point could never be reached in ordnance, the length of which was limited by practical considerations of weight and space. The 12-inch rifled gun, short as it was, was 4 feet longer than the smooth-bore 68-pounder, which not long ago was thought a large piece; and if its full instead of its battering charge were taken, it would be found that there was room for more expansions than had been stated in the Paper. The large number of expansions shown in the tables relating to the Britten 32-pounder and 15-inch guns were obtained, because the charges were so small; in the latter only $\frac{1}{13}$ to $\frac{1}{16}$ of the weight of shot. The number of expansions in the service heavy guns were—

	Battering Charge P.	Full Charge R. L. G.
12-inch gun (25 tons) . . .	6·6	9·6
10-inch „	5·7	8·08
9-inch „	5·4	7·5
8-inch „	5·5	7·1
7-inch „ (7 tons)	6·6	9·0

The Author's table of muzzle velocities and energies was of little value, in estimating the respective powers of guns differing in calibre when fired at ordinary ranges; if guns were used at close quarters there would be no need to rifle them. He considered it useless to compare the rude monster smooth-bored guns of America with the heavy British rifled pieces; for, besides the inaccuracy of fire and great loss of power as the range increased with the former, the nature of the action of the gas in the bore was very

different from that in a rifled gun. At the same time he thought the Author had done good service to artillery science, in calling attention to the necessity of adapting means to the desired end in the construction of ordnance, and of determining the requisite conditions of charge, calibre, and length of bore.

Captain Dawson, R.N., said he had no personal knowledge of the construction of guns, his experience being unfortunately confined to their destruction. For twenty-five years he had dealt with heavy guns, and for eleven years he had been engaged in artillery instruction, in preparing gunnery instructors for the fleet. In that capacity it had been his duty to learn, from his brethren of the Royal Artillery, a great many novelties which were stated to be gunnery principles; but which unfortunately had repeatedly to be unlearnt. Indeed, a new set of artillery theories was usually furnished to the Navy with each new system of rifling, and the conclusion he arrived at was to believe nothing that could not be verified by a critical inspection of the original data. Amongst the systems that had come before him, but which he had not to teach, was Mr. Britten's plan of rifling cast-iron guns. Looking into the practice tables, he could not understand why that system had not been adopted for rifling the existing stock of cast-iron and of gun-metal guns. The official reports and tables showed that the lead-expanding system had a remarkable effect upon the endurance and longevity of cast-iron guns; and it was demonstrated to be a cheap way of converting bad artillery into what was good for the second-rate duties in war. There was a large stock of brass guns utterly useless, as the French or service system of rifling could not be applied to them; also a large stock of cast-iron smooth-bored guns on hand. These materials existed in guns up to $4\frac{3}{4}$ tons weight. In his opinion, no system of rifling had been produced better adapted than the lead-expanding projectile for the existing stock of weak gun-metal and cast-iron guns, if they were to be made useful at trifling expense, for firing heavy shell at low velocities, which would be serviceable only for the secondary purposes of warfare against wooden ships, in bombardments, and on shore. But when it came to manufacturing new guns, the element of weight must be compared with that of work; and not only must the interior of the gun be looked into, but the trajectory and the other end of the range must be looked at also. A gun was merely an arm to wield a given tool; the tool was the shot; the purpose of the tool was to bore a hole; and the larger that hole could be bored in the thickest iron plate, within useful fighting range, say 1,500 yards, the better that tool was. But it was essential that the tool

should bore the hole, or, in other words, that perforation should be ensured. Would the proposed shots of large diameter and low velocity bore a hole at 1,500 yards? and if so, would they do the greatest amount of damage inside the armour backing that could be inflicted? On the one side Sir Joseph Whitworth, with his long iron bearing, correct centreing, and mechanical fit, represented the long shot with a small-bore gun; and on the other, Mr. Bashley Britten represented the large-bore gun and short projectile. The question was, which of these would make the best work? He could understand that the lead-expanding system would be admirable for a shot of large diameter, and short length, propelled by a small powder charge, if a low trajectory and consequent accuracy at unknown distances were not desired. But if the first object of rifling was to rotate or spin the shot throughout its course, that system of gripping the shot at one extremity was not suitable for rotating long projectiles moving at high velocities. The question which occurred to his mind was, whether the Author had not been endeavouring to build such a gun as would suit the lead-expanding system of rifling. But all experience showed that the lead-expanding system could not be employed with heavy charges, which must be used for high velocities and low trajectories, and perforations of armour. This plan was tried in 1864 in a 7½-ton gun with only 25 lbs. powder charges, when it was found that the lead became fused, and that its attachment to the shot was not sufficiently strong to stand the shock of the charge and the strain of rotation. If that were the case with only 25 lbs. of powder in a 7½-ton gun, he supposed the same fusing and breaking away of the lead would occur in a higher degree as the amount of powder was increased in a heavier gun, to obtain a low trajectory and good perforation.

In the principle of construction adopted, the Author appeared to have followed Mr. Parsons, or Major Palliser; for he had put a wrought-iron tube inside a cast-iron case. If it were desired to strengthen a weak gun, that would, as regarded expansion, be the best plan of applying those two materials; for when the high temperature was formed in the powder chamber, the wrought iron would expand more rapidly than the cast iron, and the outer jacket would thus be forced to do the intended work. The great difficulty all gun-builders had to contend with was to get the outer material to do its fair share of duty. But in gun-building there were other things to be considered besides the expansion of the material. Comparing the proposed plan, in this one particular, with the present service system of putting a hard steel lining

inside a wrought-iron coating, the system now advocated, with regard to the one point of expansion, would appear to be more correct than the service system; because when a Woolwich-built gun got heated after the rapid firing of heavy charges, the steel lining would, after cooling, return to its former diameter. But the limits of elasticity of the wrought-iron coils being less than that of the steel lining, they would, after excessive expansion and many rapidly succeeding concussions, remain extended, leaving a space between the inner lining and the outer coating; and on resuming fire after the gun had cooled, the steel lining would have to sustain all the strain, and the gun would be put to a great test. It was, however, proposed to build guns on this system, not because it was stronger than the service one, but because this plan was weaker and cheaper. The system of construction was based on the assumption, that the present guns were too strong, and therefore a cheaper and a weaker gun was proposed. But if the service-guns were too strong it would be more sensible to put more powder and heavier projectiles into them; for the object to be aimed at was to strike the hardest blow, with the lowest trajectory, from a gun of given weight; therefore if the service-gun was too strong, by all means let more powder be put in, and a higher velocity be obtained, or let its weight be reduced. A gun should be strong enough to fire as much powder behind its shot as it could usefully consume. It was well known that with a given weight of shot a given gun could not when cool usefully consume more than a certain quantity of powder, and that all powder beyond that quantity was simply waste,—thrown out of the bore, unconsumed. But in the service-guns of the present day greatly reduced pellet powder charges could only be employed. And what was wanting in powder was made up in name, for these greatly reduced charges were dignified by the delusive epithet of "battering charges." But if the guns were too strong, how was it that there were official instructions that the 18-ton gun was only to fire 250 so-called "battering charges!" and that was its life: whilst the 25-ton gun was officially limited to only 100 "battering charges!" and that was its life? No official rule had as yet been laid down with regard to the 35-ton gun; but the healthy life of the first one ended at about 68 rounds, firing pebble powder charges below that which it could usefully consume. This limited longevity was a serious point, for the 'Glatton,' a fine turret ship, had only two 25-ton guns on board. If each of her one hundred fighting men were to fire two rounds in the course of a year, to train them in the use of the guns—and that was a small amount of eye-

training to make marksmen—those 25-ton guns would be disabled at the end of a year. But there would be a vast difference in the life of a gun between rapid continuous firing, which heated the gun and gave much larger powder consumption, and occasional firing at long intervals of time—perhaps months between each round. Yet it was said guns were too strong, guns which had never been tried with rapid continuous firing for even a hundred rounds. Even in slow, deliberate firing, when guns were cool, they were constantly mutilating or disabling themselves; much more mischief then might be expected in the rapid firing of a naval engagement. A great deal of nonsense was talked about gunnery principles. He had the greatest respect for figures, but it was only necessary to take wrong premises, and any imaginable conclusion might be drawn from them. The Author had done good service in divesting this subject of a great deal of the false philosophy and baseless hypothesis usually applied to it. It had been truly said that after an expenditure of £4,000,000 on rifled artillery, the subject was still a system of guesses from first to last. Given a gun of a certain weight, what ought to be its calibre and charge, and what the weight, length, and rotation of its shot? Nobody knew. The "rule of thumb" was artillery science.

The Author had massed together figures in delusive groups, and had made much of the 20-inch 50-ton American smooth-bore gun. He found from "Holley on Ordnance," that it fired 100 lbs. of powder, instead of the 200 lbs. charge stated. He agreed with the remark, that to compare the endurance, or the total muzzle blow, of the smooth-bore gun with the rifled gun was puerile. The chief of the American Ordnance Bureau reported to Congress last June, that "cast iron is not believed to be suitable for heavy rifled guns; other materials should be experimented with." And, while the Americans continued the use of cast iron for smooth-bore guns, the chief of the Ordnance Bureau reported that "it is thought that a still further improvement may be made by a change in the treatment of the metal in the furnace, and experiments with this object are now progressing."

In the Report of the Ordnance Select Committee on Coiled Wrought-iron Inner Tubes for Ordnance, it was stated:[1] "The last and perhaps most serious objection is, that cast-iron guns lined with coiled iron are said to be inherently weak and necessarily unsafe. It will be seen that neither Sir W. Armstrong nor Major

[1] *Vide* Report 16th March, 1868, p. 8.

Palliser rely on the coiled barrels for longitudinal strength, which must, according to their view, be derived from the cast iron alone." Yet there had been spent more than twice their original cost on the conversions thus spoken of; and now an argument was advanced in favour of the construction of guns *de novo* on a principle pronounced "inherently weak and necessarily unsafe." The guttering or erosion of the interior of the service guns, that had been referred to, occurred with a lining of toughened steel, and it was certain that with an interior of soft wrought iron the evil would be far greater.

In Table II. the pressure on the 12-inch 35-ton gun, with 120 lbs. of pebble powder, was given as 27 tons per square inch; but he found it had reached 66 tons. It was useless to build arguments upon pressures which varied so much. The pressure tabulated for the 115 lbs. of pebble powder was 20 tons, but that charge had reached 44½ tons powder pressure. This divergence was no doubt caused by the wriggling motion of the projectile, hobbling out of the bore upon two hard buttons, aided by the increased consumption of powder in successive rounds, owing to the heat developed by such large charges.

The Author had fallen into a mistake, in the statement that the 35-ton gun had cracked whilst firing a charge of 130 lbs. of pebble powder. The 130 lb. charge was fired out of the 11·5-inch bore; but when the gun cracked it had a 12-inch bore, and was being fired with charges of 120 lbs. of pebble powder, four of which varied in local pressures thus: 46, 66, 44, and 37 tons, every one of which was greater than the minimum tabulated in the Paper. The fact was, powder pressures had nothing to do with the crack in the 35-ton gun, or with the destruction of any other British gun. These guns were destroyed outside the area of maximum powder pressure, by the hammering action of their wobbling projectiles, or by the breaking-up shell, owing to the unmechanical system of rifling which threw out the fuzes.

Of thirty-seven guns, of the total weight of 430 tons, being a few of those mutilated in various degrees or burst, in the course of the last seven years, since the "French" system of rifling was adopted, he found that two had burst explosively, throwing their shattered fragments hundreds of yards; eighteen, of 152 tons gross weight, had been permanently disabled; five were obliged to cease fire for a time; and twelve were less seriously injured. The "Cemetery of Suicides" at the Royal Arsenal contained many other specimens, of which he could not speak positively. But of

the thirty-seven guns so mutilated, disabled, or explosively burst, not one had suffered within the area of the maximum powder pressure. All had been injured outside the point where the base of the shot was when the maximum powder pressure was relieved. In short, the guns were not destroyed by the powder, but by the projectiles, which were rifled on the worst possible principle. The wriggling shot hammered its way out of the gun, abrading the grooves and lands all along the bore, breaking up the shell, and occasionally wedging itself in the gun, and causing an explosive burst. The first gun of the thirty-seven thus referred to was the original "Woolwich" rifled 7½-ton gun of 1865. This was so hammered along the bore whilst firing 567 rounds, that it was directed to be fired "under precaution" against bursting; the lands and grooves having been abraded and distended by the hammering action of the wriggling shot in its effort to escape out of an increasing spiral, which presented an ever-increasing resistance to its escape.

There was considerable experience in the Navy as to mutilating and disabling heavy guns; for no less than eighteen had suffered injury on shipboard since 1869, and this was going on every day. Almost every ship of war that was paid off had some of her heavier guns injured internally, by firing from them the eight rounds per quarter allotted for practising the crew in the use of the weapon. When the 'Monarch' was paid off lately, every one of her four 25-ton guns was found to have been slightly injured after an average of 35 discharges; though some of them had only fired 9 rounds in the course of three years, with greatly reduced, or so-called, "battering" charges. It would be a useful contribution to scientific truth to examine *seriatim* the particulars of the injuries sustained by each damaged Woolwich gun. It might thus be learned exactly where, how, and why the guns gave way. What he wanted to urge, with reference to disabled British guns, was that, so far as his researches went, not one of them failed by powder pressure. They were disabled in a variety of ways, all connected with unmechanical rifling. Only two of the whole number had burst explosively during the last seven years; and it was a mercy that those violent bursts had not occurred on crowded decks on shipboard. It was known how the weak and cheap guns with increasing spirals had burst in American ships, and killed and wounded forty-seven men. A Russian frigate in the Baltic had forty-two men killed and wounded from the explosive bursting of a block-steel gun. One of the mixed wrought-iron and cast-iron

converted guns was amongst the British guns recently burst; and its seventy-six pieces were thrown over an area of 580 yards by 150 yards. It might be imagined what the effect of that would have been on the crowded decks of a ship. The other explosive burst occurred with what was called the over-strong Woolwich manufactured gun, which burst violently at the first round. It was a 12½-ton wrought-iron coiled gun, with steel lining. Even the temporary disabling of naval guns might inflict serious loss upon the country: for, in a naval action, to be obliged to cease firing for an hour might result in the ship being carried into the enemy's port. Differing as he did from the Author as to the cure for these evils, he could not but think that Mr. Britten was entitled to their best thanks for his efforts to penetrate the secrecy which withheld from the public the knowledge that the life of British guns was limited and uncertain to a dangerous extent. He hoped that one result of this discussion would be to promote inquiry into the system of rifling which produced such suicidal results.

Mr. P. M. Parsons thought the observations in the Paper relative to ascertaining the pressures exerted by the explosive gases on the interior of guns were most important. He drew attention to the necessity of this eight or ten years ago, when he pointed out that if engineers knew what strains had to be provided against in the construction of ordnance, they would be able to make guns of the requisite strength and endurance. At that time it was supposed the ultimate pressure of the gas of ignited powder amounted to about 17 tons per square inch. The introduction of the pressure-gauge, described by Lieutenant Jones, showed that this was a fallacy, and that the pressure was much greater, although to his mind the apparatus was not perfect. The fact of the piston not being flush with the surface of the bore altogether altered the conditions, because the gas, which was of nearly the specific gravity of water when the powder was first ignited, would have a powerful percussive action rushing up the tube, and would cause the instrument to register a higher pressure than actually existed in the gun. Although he thought the instrument could not be relied upon to give the actual pressures with exactness, yet it would indicate comparatively, and with sufficient accuracy, the pressures with different charges and in different sized guns, so as to enable a fair estimate to be made, if checked by calculation, of the relative strength required in each.

He considered, from experiments in America as well as in Eng-

land, that cast iron was utterly useless *per se* for rifled guns. The American Bureau had reported directly against cast-iron rifled guns. No solid gun, whatever its thickness, would bear a greater pressure per square inch than the tension of the metal of which it was made. The elastic strength of the very best cast iron could not be taken at more than 4 tons to the square inch; and, allowing for the assistance the metal round the charge derived from that at the end and in front of it, a total resistance of more than 6 or 8 tons to the square inch could not be calculated on. As in the smallest rifled gun the pressure was from 15 to 20 tons per inch, it was impossible, in a gun made solely of cast iron, that sufficient strength could be obtained to sustain the strain from the explosion of gunpowder, if service charges were employed.

He could not agree with the Author that the service guns were stronger than necessary. Indeed he thought it could be easily demonstrated, that the guns, particularly of large calibres, were not strong enough. If the pressure generated by the gases, as registered by the indicator in guns of different calibres, was compared with that estimated by the weight of the shot for each square inch area of the bore, one would corroborate the other, and it would be found that as the calibre was increased the pressure per square inch also increased. If that pressure were compared with the actual strength of the guns, calculated by Barlow's formula, it would be seen that the guns were nearly of the same strength per square inch in all calibres; whereas the pressure of the gas increased from about 15 tons per square inch in the 8-inch gun to from 40 to 60 tons in the 12-inch gun. He had calculated a few of these for comparison with the results obtained from trial with the pressure-gauge. The gauge indicated

In the	8-inch gun	a pressure of . . .	15	tons to the inch.
„	10-inch „	„	19 to 21	„ „
„	12-inch „	(600 lb. shot) a pressure of	27	„ „
„	11½-inch 35-ton gun	„	46 up to 60	„ „

In calculating the strengths, he took sections through the bore of these different service guns, and applied to them Barlow's formula, assuming each tube would do its fair share of duty. Taking the elastic limit of wrought iron at 10 tons to the inch, and that of steel, tempered in oil, at 28 tons to the inch, the 9-inch gun had a strength of 25 tons to the inch; the 10-inch gun, 26·8 tons; the 11-inch gun, 28·7 tons; the 12-inch gun, 27·6 tons; and the 35-ton gun, 28 tons to the inch. Again, by an analysis of the weight of the shot in proportion to the area of its cross section, it

would be found that the weight of shot per each square inch area of the bore was

In the	8-inch gun	3·5 lbs.
„	9-inch „	4·0 „
„	10-inch „	5·6 „
„	11-inch „	5·6 „
„	12-inch „	5·3 „
„	12-inch 35-ton gun	6·19 „
„	11½-inch „	6·74 „

It was therefore evident, if a pressure were required of 15 tons, whether ultimate or mean, to put a shot of 3 lbs. to the inch of area in motion, at a given velocity, it must require double that pressure to put in motion a shot of double the weight, in the same area, at the same velocity; and that accorded generally with the results of experiments with the pressure-gauge described. Yet, while it was thus shown that in the larger calibres the strain was about doubled, the strength of all the guns remained nearly the same; the 9-inch gun having a strength of 25 tons to the inch, while the 11-inch and 12-inch guns had only a strength of 28 tons to the square inch. It was on these grounds he contended the Author was in error in stating that the service guns were too strong, and he, on the other hand, thought for the larger calibres they were not strong enough. It was evident the system had been worked out in the best way. There was no dispute as to the ability of Sir W. Armstrong, who invented and developed the system, nor of Mr. Anderson, who introduced the method of tempering the steel tubes in oil; and the scientific attainments of the present Superintendent of the Royal Gun Factories, Colonel Campbell, and the practical abilities of his assistant, Mr. Fraser, who had simplified and reduced the cost of the guns, were well known. All these gentlemen had devoted their best attention to the subject, and had done all that was possible to perfect the system. Therefore if these guns were not up to the mark for large calibres, it must be due to the system being unequal to the task demanded of it, and the system could only be made efficient by important modifications and improvements. It was, no doubt, good for guns up to 9 inches calibre; but beyond that its efficiency was doubtful. The only way to improve the system was to use steel in a larger degree. Every Engineer who had tested steel knew, when mild steel was tempered in oil, the tensile strength at the breaking point was from 40 to 45 tons, and at the elastic limit about 28 tons to the square inch; while wrought iron had only a strength of 10 tons to the square inch at the elastic limit. There was, therefore, nearly

three times the strength in steel as compared with wrought iron. What the wrought-iron service guns wanted was another band of steel round the breech end of the A tube, before the wrought-iron casing was put on, and this he felt certain would be necessary to enable guns of large calibre to fire heavy charges.

Another point with regard to these guns, which the advocates of the system claimed exclusively for them, was that they did not burst explosively. That was hardly borne out by facts. The following was a list of wrought-iron guns which had burst explosively:

9-inch, No. 287, at the 104th round.
„ „ 286, „ 400th „
„ „ 222, „ 402nd „
„ burst at proof.
10-inch, on board the 'Wivern.'
„ at Shoeburyness, at the 193rd round.
And No. 320, 64-pounder, burst into thirty-eight pieces.

He did not bring this list forward to depreciate the guns, but to show that they would, under certain conditions, burst explosively; and any gun, strained beyond the elastic limit of the metal, must burst explosively with such a power as gunpowder.

He had been working for the last ten years at the system proposed by the Author, and was surprised there was no allusion in the Paper to some of the experiments he had made in support of the system; but he concluded the Author was unaware of what had been done in the matter. If that were the case, and if Mr. Britten had worked independently in the same direction, and had arrived at the same conclusions, it was an additional proof of the merits of the system. It would, no doubt, be gratifying to the Author to learn, that the experiments he had made with guns so constructed fully corroborated the views expressed in the Paper; only the Author did not go far enough. These guns proved capable of firing higher charges than wrought-iron guns; they did not burst explosively, and he believed they were the strongest and safest guns that could be made. His first proposal to combine wrought iron with a steel or iron tube fitted into the guns was submitted to the Ordnance Select Committee in 1860. His idea was to put a tube of wrought iron into the gun at the muzzle. Two guns were made on this plan, and proved very successful. The Ordnance Select Committee reported that the 68-pounder sustained 71 rounds with increasing charges, which exceeded in endurance every gun previously strengthened externally. In 1862-63 Major Palliser brought forward a similar proposal, and

that plan of construction had been adopted into the service. But he soon saw that it was impossible to get sufficient strength in the gun with the tube put in at the muzzle, as the size of the tube at the breech end was restricted by it, and that a greater amount of strength could be obtained by putting in the tube from the breech, as then the breech end of the tube could be made of any size. He also came to the conclusion, which subsequent experiments confirmed, that steel was better for the purpose than wrought iron. He brought this gun before the authorities in 1863, and continued for a long time to urge a trial of it. Ultimately it was submitted to the Emperor of the French; and a gun converted on this plan was tried in France in 1865. It was a 30-lb. gun, and was lined with a tube of mild steel tempered in oil, having a second tube, also of tempered steel, shrunk on to its breech, and with a breech screw screwed into the breech end, bearing on the end of the inner tube. The tube was made in England, and was sent to Cherbourg, where it was fitted into the gun. That gun was tested at Gavray; it fired 510 rounds, with a charge of 8·8 lbs. and a 64-lb. shot; and 500 rounds with a 16½-lb. charge and 100-lb. shot; and then the gun was perfectly sound. After that the same gun was fired with a charge of 26½ lbs. and a shot of 132 lbs. Ten rounds were fired with that charge; and at the eleventh round the gun burst in the chase, the breech end of the gun and both tubes remaining intact. The gun was never intended for such a charge. Its great length brought the first shock of the explosion beyond the reinforce, and it was only in consequence of this that the gun failed.

Some time afterwards, he was offered a contract by the British Government to convert a 68-pounder on his system, to fire a charge of 30 lbs. of powder, and a shot of 150 lbs.; and a gun was converted by him. There was little difference between this gun and the French gun, beyond some slight improvements in the details. When the gun was completed, the Ordnance Select Committee first fired from it two rounds with charges of 37½ lbs. This no doubt strained the gun more than all the subsequent firing, which was with 30-lb. charges and 150 lb. shot. At the 165th round, the cast-iron casing began gradually to open towards the breech end; and when this indication of bursting appeared, the firing was discontinued. The result of the trial proved that guns thus constructed were capable of firing double charges, as compared with the service guns, in proportion to the weight of the gun, and that even with such excessive charges they would not burst explosively. In the service guns, from the 8-inch up to the 12-inch bore, the

weight of battering charge, per ton weight of gun, varied from 3 lbs. to 3·9 lbs.; and the weight of shot from 20 lbs. to 24 lbs. In this converted gun, though composed of $\frac{2}{3}$rds of cast iron, the weight of the charge was 6 lbs. per ton weight of gun, or nearly double that of the service guns; and the weight of the shot was 30 lbs. per ton weight of gun, which was 50 per cent. more.

High velocities of shot were wanted, for as the destructive effect increased as the square of the velocity, a lighter shot and a smaller gun would thus do the work of heavier projectiles and larger guns. It was not possible, however, to get high velocities from low-pressure guns. The initial velocity of the shot from his gun was higher than that of any gun in the service at the time, being 1,490 feet per second. His system of rifling was also different. Instead of grooves, the gun was rifled by ribs raised on the surface of the bore. By employing ribs a quicker twist could be given to the rifling. This gun had a twist of 1 turn in 30 calibres, and the strength of the gun was not impaired, as was the case when grooves were employed. The firing was admitted to be most accurate, and it exceeded the range of the service guns considerably. He attributed that partly to the quicker twist, and partly to the form of the shot, which was rounded at the end. If a shot with a flat end was discharged at a high velocity, a vacuum was left behind it which retarded the shot; but by making the shot slightly rounded, a vacuum was not formed to so great an extent. Round-ended shot had been tried before, but he did not think the difference of range was so clearly shown as in this instance, and the advantage of giving the shot a rounded base had not been so fully recognised, because in former cases the shot had been discharged at a velocity below that at which air rushed into a vacuum.

Captain Dawson, R.N., said, in his endeavour to show that the service guns were not too strong, he had no intention of implying that they were originally built too weak. It was impossible for any gun, however built, to withstand the strains brought upon it by studded projectiles wriggling their way out of an ever-varying curve, and experiencing the maximum resistance from the rifling when at their highest velocities.

Mr. Stuart Rendel observed that the immunity of coil-built guns from explosive bursts had been questioned, and the explosive bursts of four heavy guns had been mentioned. He believed of the four guns named, one was a 9-inch gun that burst at proof. In this gun the service method of building up the gun, of cylinders shrunk one over another, had been abandoned. To that extent the

gun failed to represent a leading feature of the service system of construction. In consequence of the burst, all the 9-inch 12-ton guns subsequently made were constructed with a double layer of coils instead of a single mass. Another of the four guns alluded to was, he believed, a gun that burst explosively, simply because when being used for experiments with shell loaded with gun-cotton, a large shell so loaded burst prematurely in the bore, and of course broke up the gun. A third was an early experimental gun made of wrought iron of too hard a character. This gun undoubtedly burst explosively, after 400 rounds, and after giving plenty of warning. He had never been able to find any completely satisfactory explanation of the explosiveness of this burst; but it was, he thought, the solitary instance in which a wrought-iron coiled gun, on the built-up construction, had failed with violence, though not without warning. This, out of the vast experience acquired with six thousand guns, seemed hardly sufficient ground for depriving the system of the advantage long claimed for it of non-liability to explosive bursts.

Captain Simpson, U. S. Navy, considered the Paper treated the subject under two heads: 1st, as to whether the material employed was in all respects the most proper, the Author evidently taking the Woolwich gun as the standard of reference; and, 2ndly, as to whether the power was used to the best advantage. The entire Paper showed the result of patient study, and exhibited great ability in the grouping together of facts and figures.

The Author cited the case of the 32-pounder gun, fired with a charge of 10 lbs. of powder and spherical shot, with the same gun rifled, fired with half the weight of powder and a projectile of 50 lbs. weight. The *vis viva* developed at the muzzle of the gun was much less in the latter case than in the former; but the range and accuracy of the heavier projectile were much increased, and the force was continued long after the lighter shot had ceased to act. The strain on the gun could be approximately measured by the proportion of the *vis viva* at the muzzle in the two cases. In this comparison the economic use of the power employed was shown to be in favour of the reduced charge and the heavier projectile, and there could be no doubt that a transformation of guns, such as was proposed, would greatly increase their power. The point of the argument was illustrated in this experiment. The smooth bore with 10 lbs. of powder was a high-pressure gun; the same gun with the smaller charge was a low-pressure gun, putting in motion a heavier projectile under more favourable circumstances for both powder and gun, the powder

being allowed time for more expansion, and the gun being less strained. The projectile also, from its greater weight, possessed more power to overcome the resistance of the air. In the case of two spherical balls, one larger than the other, the actual resistance encountered by the larger ball was less than that encountered by the smaller, in consequence of its greater weight, in which lay its power of overcoming resistance. Much greater, then, was the ease with which a heavier projectile would overcome the resistance of the air, when compared with a lighter one of the same diameter. It was this first principle in the theory of projectiles that the Author asserted had been lost sight of; and he argued that this theory, so well recognised in the case of spherical shot, applied especially in the case of shot from rifled cannon; in a word, that high-pressure guns were inconsistent with the rifle principle. If this point could be accepted, his argument was that the material now used for cannon was unnecessarily strong and expensive. As a proof of the sufficient strength of the metal proposed, reference was made to firing with a 68-pounder, the gun actually not bursting until tested with a charge of 7½ lbs. of powder and a projectile of 450 lbs. weight, having previously fired a succession of series of 10 rounds each with projectiles of 90 lbs., 135 lbs., 180 lbs., 225 lbs., 270 lbs., 315 lbs., 369 lbs., and 405 lbs. With such a specimen of endurance of cast iron, the Author had a right to confidence in that material.

But to illustrate still further the theory of the advantage of a more economical use of the power developed, experiments with the 10-inch Woolwich gun were cited, where the usual service charge of 70 lbs. was fired with increasing weight of shot. In this instance the weight of the projectile was increased from 300 lbs. to 1,000 lbs.; the pressure on the gun rose from 15·6 tons per square inch to 22·1 tons per square inch; but the *vis viva* per lb. of powder increased from 68·8-foot tons to 77·5 foot-tons, showing a decided economy in the application of the power.

These two examples were quoted to indicate the ground the Author had for his faith. Captain Simpson thought a careful examination of the Paper would show that, so far as an economical use of the power developed in a gun by the combustion of powder was concerned, it had certainly been proved that the advantage must lie with the large-bore over the small-bore gun. There being no space for expansion in length, room must be found in the width or diameter of the bore.

In the U. S. service the advantage of large-bore cannon had long been recognised. The late General Rodman, of the U. S. Ordnance

Corps, and Admiral Dahlgren were both early impressed with the importance of large ordnance, and were active in their several branches of the service in introducing it. The 9-inch and 11-inch Dahlgren guns, with which the U. S. Navy was armed, had long been the admiration of foreign officers; and the economic use of the power developed in the charge was not one of their least recommendations. The strength of these guns was also very great. He had frequently fired the 11-inch gun with a charge of 30 lbs. of powder and solid shot weighing 180 lbs. This charge was the battering charge of the gun, but the powder was similar to the much-abused R. L. G. used in the British service.

The late Admiral Dahlgren was so thoroughly confident in the strength of his guns, not one of which ever burst in service, that he did not embark at an early day in experimenting with large-grained powder. The credit of originating this investigation was due entirely to General Rodman. The Ordnance Bureau of the Navy Department, however, under its present able chief, Commodore Case, was now closely following up experiments on this subject, and the results obtained thus far were most satisfactory. These experiments were not really necessary, so far as the American smooth-bore ordnance of general use in the Navy was concerned. Although the authorities were moving slowly towards the adoption of rifled cannon, they were trying to move surely, and they had thought it best to begin with the powder, which, after all, was the most important element, as being the power to control and the power which produced the effect. The United States authorities were consulting the most economical method of changing the character of their ordnance; and if it was found possible so to control the gunpowder as to give high velocities from their existing cast-iron guns when rifled, without increasing the pressure to a dangerous point, they would certainly carry out the change.

In reference to gunpowder, the U. S. Government propounded to the manufacturers of the country a project requiring a certain velocity with a pressure not to exceed a certain amount. The Messrs. Dupont, of Wilmington, in the State of Delaware, accepted the proposal, and had been experimenting with great success. He quoted the pressures and velocities given by two kinds of powder:—

Samples	A. L.	32,000	lbs.	pressure per square inch	.	1,571	feet	initial velocity.
„	„	25,000	„	„	„	. 1,576	„	„
„	„	28,000	„	„	„	. 1,570	„	„
„	A. K.	21,000	„	„	„	. 1,573	„	„
„	„	23,000	„	„	„	. 1,575	„	„
„	„	26,000	„	„	„	. 1,567	„	„

The powder was mammoth powder, the size of pebble, and the firing was from a 15-inch gun with charges of 100 lbs. of powder and projectiles of 450 lbs. The simple reading of the statement went to show the wisdom of experimenting first on the powder before commencing to build a gun. The pressures varied from 14¼ tons to less than 10 tons per square inch, while the velocities varied from 1,567 to 1,576 feet per second. It therefore seemed to be practicable to use cast iron for rifled guns, if, as the Author recommended, the calibre was large, and an economic application was made of the power evolved. The calibre of this 15-inch gun must be borne in mind, as well as the smooth bore, in contemplating the result. With a gun of smaller bore, rifled, the same weight of projectile, and a lengthened cartridge containing the same weight of powder, the pressure would without doubt be more violent. But the velocity attained with the normal charge in the smooth bore was so much greater than was necessary in a rifled gun, that the charge of powder could be reduced to that of the Woolwich gun, throwing the same weight of projectile, and would still be able to produce equal results. The 10-inch Woolwich gun, with a charge of 70 lbs. of powder, threw a projectile of 400 lbs., with an initial velocity of 1,364 feet per second. The 15-inch gun block of cast iron bored to 12-inch calibre, with the same charge of powder of 70 lbs., could throw its projectile of 450 lbs. with perfect safety, and with a better and more economical development of the power evolved in the charge. He had no idea of contrasting the artillery of the two countries, and in fact he was not doing so, for the gun referred to did not exist. The Author's arguments led, however, to the contemplation of such a gun, and the experiments with American gunpowder, which gave great velocity without oppressive strain on the gun, showed that such a gun was practicable. The Rodman 12-inch cast-iron rifled gun, now being experimented with by the army authorities in the United States, was supplied with a projectile weighing over 600 lbs., and had been fired with a charge as great as 85 lbs. of powder. He could state nothing positive as to this gun; several had been tried with variations in the rifling and in the projectiles, which last, however, were all on the expansive principle; but good results had been obtained, and it was expected that success would crown the efforts in this direction.

The experience with the Parrott gun, which was more condemned than it deserved, did not discourage farther efforts with cast iron, for it was recognized that the gun was improperly constructed. An examination of the history of all these guns used in recent years in the United States showed that, though guns burst after

long and rapid firing, yet the general execution was good. With the light thrown upon the subject of the construction of cannon during the past ten years, it was remarkable how well the Parrott guns stood; and with the late improvements in American gunpowder, there seemed a fair prospect of constructing a cast-iron gun that would answer all ordinary demands. The details for such a gun, the character of the rifling, twist, form, and weight of projectile, and charge of powder, required exhaustive experiments to determine; but he was assured that the work was progressing with reasonable promise of success.

He had shown that American powder could be manufactured to give high velocity to the shot with a low pressure on the gun. He would now quote examples of another experiment, where the manufacturer was allowed to produce a pressure per square inch not exceeding 50,000 lbs., the object being to get the greatest velocity. He referred, however, first to the explanation by Lieutenant Jones of the pressure gauge, in which the cylinder used to receive the pressure was described as being made of copper. Hitherto the use of copper for this purpose had been general; but a change had been made in this respect in the United States. The change consisted in the substitution of silver for copper. The instrument had been experimented with by Lieutenant Commander Marvin, of the United States Navy, who was in charge of the experiments with the new powder for the Navy. The want of uniformity in the results led Lieutenant Commander Marvin to consider the propriety of using another metal. It had been ascertained by experiment that, after allowance for defective discs, the results with cylinders of silver obtained from the Mint could be depended upon within 1,500 lbs., while the margin of error with the copper cylinders had reached 13,000 lbs. Information on this point had been placed in the hands of General Adye, the Director of Artillery to the British Government.

The plan adopted by General Rodman was hollow casting or casting on a core, with the cooling influence of water applied on the inside, while fires were kindled on the outside. On the other hand Admiral Dahlgren had always cast his guns solid. The present Chief of Ordnance in the United States Navy Department submitted the two systems to a crucial test, by casting two 15-inch guns, one solid and the other hollow. These two guns were subjected to fire *à outrance* with 100-lb. charges of powder and solid projectiles. Both guns sustained 557 discharges without injury, when the solid cast gun failed, the hollow cast gun enduring 597 fires. The result was accepted as in favour of the hollow casting,

but the endurance of both guns was certainly such as to inspire confidence in a cast-iron smooth bore, fired with 100 lbs. of mammoth powder. The powder used in the trial of these guns was taken from a stock on hand, which gave a pressure per square inch of from 45,000 lbs. to 51,000 lbs.—a pressure much greater than that from powder now used in the service.

He was a warm advocate of cast iron for guns, where large calibre afforded an opportunity for the economical use of the gases. But, in service, guns of different calibres were required, and it was not always possible to place on board vessels heavy guns of large calibre destined to perform what might now be called the primary duty of naval ordnance, viz., punching iron.

The cast-iron 32-pounder, converted, as Mr. Britten proposed, could do good secondary artillery work, quite equal, he thought, to the Palliser converted guns now in the service. The large cast-iron 12-inch rifled gun under trial in the United States might prove successful; but of this he did not feel sure at the present condition of the experiments. A lighter gun than the last was, however, required for the armament of fast cruisers at sea, in which the economy of the forces would have to be disregarded, and where the greatest possible striking power must be developed irrespective of the strain on the gun. For this purpose cast iron would be insufficient. The Woolwich gun had been referred to in the Paper, and had been placed in comparison with a gun proposed by the Author. The construction of the Woolwich gun was well known. He did not now allude to the Armstrong gun, made up of many thin coils, with its breech piece, not coiled but forged, in contact with the tube, to give strength to resist longitudinal strain. He referred to the Fraser gun, as manufactured at Woolwich, where the coils were larger and were brought immediately in contact with the tube, the strength to resist longitudinal strain being supplied by the greater thickness of the coils, and by the end-welding to which they were subjected in the formation of the massive jackets. In the proposed 15-inch rifled gun, an inner tube of steel was jacketed with wrought iron to reinforce the tube about the seat of greatest pressure, the whole being cased with cast iron. The Author did not insist upon the many parts which appeared in the drawing, and which would no doubt be challenged by artillerists. The gun might then be taken as an inner tube of steel, one breech coil of wrought iron, and an outer casing of cast iron. Thus the only difference in the two designs consisted in the jacket or outer casing—in one it was made of wrought iron, in the other of cast iron. The question was, did the cast iron possess strength sufficient

to perform the work demanded of it? He thought this question was answered in the affirmative, by experiments made on a converted gun of Mr. Parsons.

In October, 1871, he reported on the Parsons gun to his government, and he would give an account of experiments on a gun converted on this system. The point to which these remarks referred was as to the sufficiency of the cast-iron outer casing. The gun was formed of an inner tube of steel, reinforced with a steel jacket, and enclosed in a cast-iron outer casing. The reinforce extended to the trunnions. The reinforced tube was introduced from the rear, a block of steel was set up close to the rear of the tube, and the rear of the piece was closed by a cast-iron block, representing the cascable. The first experiments made with a gun converted on this principle were at Gavray, France, in 1865. The French report showed that the gun was an ordinary 30-pounder, French measurement. The tube was rifled, and a studded projectile was used. The firings endured by this gun before rupture took place were—

500	rounds,	with	8·8	lbs.	of powder;	projectile	69½ lbs.
500	„	„	16·5	„	„	„	100·2 „
10	„	„	8·8	„	„	„	69½ „
11	„	„	26·5	„	„	„	132·3 „

It was apparent from this that the endurance of the gun was immense. The charge that produced rupture placed the projectile, weighing 132 lbs., in advance of the steel jacket which reinforced the tube, yet it was not till the 11th round with this charge that the gun yielded. Unfortunately, the extreme strength of this construction, here tested to the utmost, could not be compared, or brought into direct contrast, with that of any of the other built-up guns now in use. The cost of constructing built-up guns precluded the additional expense that would be required for testing one of a lot *à outrance*. The plan to ensure safety, as practised in England, was to keep one gun of each calibre in constant use at Shoeburyness, so that its number of fires with a projectile would always be in advance of any gun of its class afloat. A gun bursting at Shoeburyness after a certain number of fires would establish the number of fires to be allowed to any gun of its class in the service. The conclusion in the French report seemed to be eminently just. It was that the gun would have been safe and efficient with a charge of 15 lbs. of powder and a projectile of 90 lbs. No doubt the battering charge for use against iron-clads could have been raised to 20 lbs., a charge sufficient to drive a projectile of 90 lbs. through

6 inches of armour. It was impossible to say what endurance might be exhibited by other guns when tested *à outrance*, but it was safe to assert that no gun ever tested to extremity had exhibited such endurance; and this was the character of a high-pressure gun which he considered requisite for light cruisers.

This system was next subjected to trial in 1868, when an English 68-pounder of cast iron was converted into an 8-inch rifle. The gun was designed by the inventor to fire a projectile of 150 lbs., with a charge of 30 lbs. of powder. This proposition would seem to have been one of sufficient magnitude, considering the great calibre of the gun in proportion to its weight; but the test did not satisfy the Committee appointed to make the experiments, for it was decided that the gun should first be tried with two charges of 37½ lbs. of powder, being $\frac{1}{4}$th the weight of the projectile. This mode of procedure had the effect of damaging the construction as much as possible before the regular trials were entered upon. In the report he made on this experiment, the expansions of the bore at successive stages of the firing were shown by a table. At 12 inches from the bottom of the bore the tube expanded ·014 of an inch during 114 rounds with the normal charge, while during the two discharges with 37½ lbs. of powder the tube expanded at the same point ·042 of an inch. The effect produced at this point with the 2 fires with the inordinate charge of 37½ lbs. was thus three times as much as was produced by 114 rounds with the normal charge of 30 lbs. Evidently the construction was tested at the outset beyond all reason, and it was only surprising that the gun endured 165 rounds. At the end of that number of fires, it was discovered that the cast-iron casing was cracked, as well as the jacket reinforcing the tube. The only way to account satisfactorily for this result was to conclude that the steel jacket was shrunk on too tight. The interior tube remained intact, but its full measure of strength was evidently not called into play, as, if it had been it would have yielded first, the object of the jacket being to reinforce the tube when its limit of elasticity had been reached. The tube in this case was apparently permitted only to exercise a portion of its power. The contraction it experienced from the jacket prevented it from utilising all its inherent strength, and the strain it should have borne was thus transferred to the jacket, which was not able to do all the work. This failure was due, then, to an error in the mechanical application of the system. The gun weighed only 5 tons, and the normal charge proposed by the inventor was equal to the service-charge of the 12-ton Woolwich gun. These two instances of ex-

periments with guns, in which the outer casing was of cast iron, bore, he thought, directly upon the question propounded by the Author as to the material.

The results of most crucial tests were in favour of the substitution of cast iron for the more expensive material in the outer casing of the Woolwich gun. In other parts of Mr. Britten's gun he noticed a repetition of the weakness of the Woolwich construction, to which he attributed the failures of the tube of the Woolwich gun. The advantage of homogeneity in the wall of the gun had been insisted upon by Sir Joseph Whitworth and by Sir W. Armstrong; and Sir W. Armstrong and Colonel Campbell, in their testimony before the Ordnance Committee on the 35-ton gun, both recommended that the gun should be made of wrought iron, but that steel was indispensable for the tube. Now steel possessed a property of elasticity which it could not part with; and this property was the discordant element in the Woolwich gun. By shrinking on the wrought-iron jacket as the Author proposed, this elastic property of the tube was attempted to be suppressed. Now, the metal surrounding the tube was malleable, and after repeated shocks it was driven away from the tube; for the tube, until its elastic limit was passed, would return after each discharge to its normal dimensions. Each successive discharge condensed more and more the wrought iron in contact with it, until at last the surfaces were no longer in close contact as at first; the tube was then unsupported, and must crack. This was always the result with the gun after many fires. It was strong and powerful as long as the tube was supported, but after 250 fires with the 8-inch and 9-inch guns, they were considered unserviceable; in fact, the 11-inch 25-ton gun had only a life of 100 rounds, and the 35-ton gun had cracked its tube at the 64th round. The guns did not burst, but the tubes cracked, and the gun was unserviceable, the only difference being that no lives were lost by sudden explosions. Mr. Britten surrounded the steel tube with a wrought-iron jacket, subject to the same chances of failure, if the same pressure was brought to bear upon it, as in the smaller bore Woolwich gun; but this was avoided by a larger calibre and a more economic use of the lower pressure developed from the charge. What the pressure might be from the charge of 88 lbs. with a projectile of 1,200 lbs. could not be ascertained without experiment; but, from the economic use that would thus be made of the power evolved, in consequence of the greatly increased area of surface on which the gases acted, it might fairly be inferred that the pressure must be less than had to be controlled in the 35-ton Woolwich gun,

where a charge of 110 lbs. was exploded in a more contracted space behind a projectile of 700 lbs. This might be concluded from Table III., in which the pressures in the 10-inch Woolwich gun with increasing weights of projectile were recorded, whence it would be observed that with 70 lbs. of powder and a projectile of 1,000 lbs. there was a pressure of only 22 tons per square inch, The bore proposed was 15 inches. If the Author was right in his estimate of the velocity for this 1,200 lb. projectile, much greater *vis viva* would be secured for the projectile, as well as greater punching power, than could be exerted by the 35-ton gun with 700 lb. shot.

The essential design of the Paper appeared to be to recommend large calibres for heavy rifled ordnance. The Author endeavoured to show that, by an economical use of the power evolved, better results could be achieved than had as yet been attained. No chimerical ideas were advanced, but experimental facts and well-known principles of science were alone dealt with. He thought the case had been proved, so far as the light gun for secondary artillery work was concerned,—in fact this had been done before by actual experiments. But as regarded the heaviest calibres for primary work from forts and from ships that could work such guns in turrets, which was now a necessity with the 35-ton gun and 25-ton gun, he considered the arguments and reasonings were such as to demand close investigation and experiment on the part of any government. Although there were no new theories in the plan proposed by the Author, yet his reasoning showed that in planning the advancement of artillery, known principles had been discarded by the authorities, who subjected cannon to more strain than they properly should be called upon to endure.

Mr. J. Imray, M.A., observed that great principles were involved in the question under consideration, which it was the duty of engineers to discuss and carefully consider. It was contended that with all the means at the disposal of the government, with the power of unlimited outlay, the net result of the official work was pretty nearly nil. It had been stated that guns to which a supposed life of 250 rounds was attributed, had practically a life of only 30 to 70 rounds. It had also been stated that the 35-ton "Woolwich Infant" was really an abortion and a failure; but it had not been mentioned that the authorities, instead of making one, had made some dozen of these guns without trying one. In the face of all this, it seemed to him that the principles enunciated in the Paper ought to be looked into very carefully. The Author had demonstrated, in a common-sense way, those principles

—principles which were recognised in engineering in the design and construction of the steam engine; and therefore, he thought, capable of being recognised in artillery. The gases used for propelling projectiles acted much as steam acted, and the whole expansive power of those gases should be as far as possible utilised. No engineer would use high-pressure steam, and blow it off before something of its expansion was utilised. The question therefore was, how, with the material used for guns, a greater amount of duty could be got out of it expansively? It was eminently a subject for civil engineers to determine, how far this principle of expansion could be carried out in artillery. In all the new guns this principle was ignored; the expansions were only 5 or 6 in the new guns, whereas in the old guns the number of expansions went up to 11 or 12. The Author had had expansions up to 22; and where the expansions had reached to 23, there was an energy of over 100 foot-tons per pound of powder, whereas with 5 expansions the energy was only 70 foot-tons. This demonstrated the great utility of the expansive principle; and that could only be effected by adopting a large bore when the length was limited. To utilise the full expansion when the cylinder itself was short, it must be made of large diameter.

It appeared that the old cast-iron guns, much as they had been condemned, had stood wonderful tests. For all practical purposes they were strong enough in their day, and, when rifled, they proved equally strong, perhaps stronger, because they were subjected to lower pressure. The officials now, however, ignored cast iron and adopted wrought iron and steel. Many people wondered how a gun constructed of cast iron, a metal of small tensile strength, resisted the immense force inside; and they thought the resistance to that force was due only to the cohesion of the metal. But there was a certain amount of resisting power in a mass of metal outside the inner ring. Supposing a gun were built up in separate staves, without cohesion, and those staves were of enormous weight, though under constant pressure, they would open out, yet with sudden pressure their inertia would keep them from opening. The exterior weight of the gun tended to prevent the outward radial recoil of the inner ring. He agreed with the Author, that to secure strength nothing was better than having weight outside in order to diminish the outward radial recoil of the inner rings. If then more weight was wanted, and not tenacity, surely cast iron was as good as wrought iron; and if for mere mass such expensive material as wrought iron or steel was used, it was like making a clock with weights of gold.

These questions were all, he thought, to be solved by the ordinary principles of mechanics; and they ought to be worked out with the object of discovering what system, not whose system, was the best.

Mr. C. W. Lancaster said the Paper seemed to raise the inquiry, whether artillery of moderate strength was sufficient, or guns of the most approved form and of the strongest known materials were necessary; whether a low velocity and a heavy projectile, or the highest possible velocity and the most powerful projectile should be adopted. He thought, at the present day, to be contented with a low initial velocity and a heavy projectile, would rather be taking a step backward. To revert to rifled projectiles of large calibre, low initial velocity, and small charges of powder, such as $\frac{1}{10}$th the weight of the projectile, would necessitate a high trajectory, and therefore great uncertainty in striking the object at "unknown ranges," while at the same time the main conditions necessary for the penetration of armour plates would be sacrificed. If, on the other hand, high velocities and heavy projectiles were to be used, the importance of the strongest possible form of gun would be demonstrated. Were this construction of gun not followed, there would be a liability of the gun bursting, of a ship being disabled, and perhaps the loss of a decisive action.

Before adverting to the rifled pieces of artillery, he would refer to a 20-inch Russian gun, made at Perm, an extremely formidable weapon, inasmuch as it projected a round ball weighing about 1,080 lbs. with a service charge of 130 lbs. of powder and a proof charge of 200 lbs., the initial velocity with the service charge being 940 feet per second. To obtain a rifled gun equivalent in power to a gun of that kind, it was necessary to revert to some of the conditions followed by British artillerists. In the 11-inch and 12-inch guns, with a projectile of 700 lbs. weight, it was originally proposed that the charge should be $\frac{1}{5}$th or $\frac{1}{6}$th of the weight of the projectile; but subsequent experiments demonstrated that in the original 600-pounder, and in the present 700-pounder, under the strain of only 115 lbs. of powder, admirable as was the construction of the gun itself, upon the well-known Fraser system, the steel tube gave way in the driving angles of the grooves. Now that opened up an important proposition. Almost any system of rifling suited a comparatively light projectile in a field gun; but where the calibre of the gun was large, and the charges $\frac{1}{5}$th, $\frac{1}{6}$th, or $\frac{1}{8}$th of the weight of the shot, the endurance of the gun depended greatly upon the nature of the rifling. Any kind of gun, whether of bronze, wrought iron, a combina-

tion of cast iron and wrought iron, or a combination of wrought iron and steel, had a certain normal strength; but directly the interior was cut into with re-entering angles, according to the depth and acuteness of the angles, so was the original normal strength of the gun reduced. That had been proved by the constantly recurring fractures of the guns; the fracture of the interior tubes of the guns always being in one direction, viz., in the driving angle of the rifle groove. If the fracture had not persistently occurred in one particular part, this might have been attributed to chance; but as in every instance the gun gave way in the right-hand angle of the rifling, there was a principle rightly and logically confirmed. The following result of grooved cast-iron and wrought-iron guns was quoted from a letter sent to the Secretary of State for War, 25th April, 1865 :—

CAST-IRON RIFLED GUNS GROOVED.

Four guns, two 32-pounders and two 68-pounders, on the Whitworth principle, all burst under 25 rounds.
One gun, 32-pounder, rifled on the Britten principle, but of 18-pounder bore, burst at the 60th round.
One gun, 32-pounder, on Scott's principle, burst at the 73rd round.
One gun, 32-pounder, Scott's principle, burst at the 310th round.
Two guns, 32-pounders, on Jeffries' principle, burst under the 50th round each.
One gun, 32-pounder, on Haddan's principle, burst at the 205th round.
One gun, 32-pounder, on French plan, burst at the 120th round.

On the other hand, the only 32-pounder rifled on his principle fired 2,000 rounds, and had been deposited, by order of the Ordnance Select Committee, in the Rotunda at Woolwich, with the history of this trial painted on the gun. It would thus be seen that his oval-bore principal of rifling, as applied to cast-iron guns, was a complete and decided success. The results of an examination of the relative trials of wrought-iron guns made in the Woolwich Arsenal, the interior tube of each gun being of steel, showed the endurance of each gun to be as follows—

600-pounder, 22 tons weight, 13-inch bore; deeply fissured in grooves, and unserviceable at the 118th round.
300-pounder, 12½ tons; burst at the breech at the 104th round.
7-inch, 7½-ton French competitive gun; deeply fissured in grooves at the 360th round.
7-inch, 7½-ton Scott gun, the steel tubes split through at the base at the 420th round.
7-inch, 7½-ton Whitworth gun; fissured 2 feet from the breech, right through the steel tube, at the 27th round.
7-inch Shunt guns; split up the grooves at the 100th round.
7-inch Frederick gun, weighing 135 cwt., with 6 grooves shunt, was found split up in the grooves for a length of 2 feet in the breech.

On the contrary, the

> 7-inch, 7½-ton Lancaster oval-bore gun, had fired 480 rounds without the slightest change or wear in the interior of the bore, with 25-lb. charges, and shot weighing 110 lbs.

This could not be the result of accident, or of the material of the gun, because the whole of these wrought-iron guns were of precisely the same construction. It was to be observed, that the destructive effect of every form of groove was in proportion to the diameter of the bore, and the advantages of the oval-bore system were developed in the same ratio.

Subsequent to the Report of the Committee on the 7-inch Wrought-iron Gun Competition, the Government ordered two guns of Fraser service construction, of 12½ tons weight and 9-inch bore, one to be rifled on the Woolwich plan, and the other on the Lancaster oval-bore system, and they directed the two guns to be tested for endurance with battering charges of 45 lbs. and 250-lb. projectiles. The first-named gun, at 600 rounds, had its A tube deeply injured, by the erosion of gas and the action of the studs, for upwards of 3 feet from base; but the latter gun, oval-bored, did not suffer from erosion in any degree like that developed in the service gun in the same number of rounds.

The 700-lb. shot of the Woolwich 35-ton gun, before being fired, rested on the bottom of the bore, and had not only to be rotated by the action of the studs, but to be lifted as well, and then projected through the bore at the rate of between 1,300 and 1,400 feet per second, thus involving a double duty. When the shot rose, the bronze studs struck against the angles of the grooves; and, with a full battering charge, in a great number of instances these studs were shorn off against the edge of the grooves. In fact, so violent was the action, that not only were there numerous instances of sheared studs, but the impress of the grooves in the gun was left upon the body of the shell, to the depth of nearly $\frac{1}{10}$th of an inch. That, he contended, was not fair play, either to the constructors of the gun, or to the country which had to pay for it. On the other hand, a projectile without the studs turned in a spiral oval form, the interior of the gun being of corresponding spiral oval form of regular pitch, would produce no undue strain on the gun, while greater accuracy and higher initial velocity were obtained than by any other system, as was demonstrated by Government Official Reports on the 7-inch Wrought-iron Rifled Guns. It was a fact, and on record, that during numerous trials

both in actual warfare and at Shoeburyness and Portsmouth, no oval-bored rifled gun, whether in cast or wrought iron, had ever burst at the breech. If, therefore, the highest initial velocity obtainable with rifled guns was the object in view, grooved guns and studded projectiles could not be preserved. But if lead-coated projectiles were to be retained, the charges of powder must be reduced to $\frac{1}{10}$th the weight of the projectile, entailing a correspondingly reduced initial velocity. Therefore, either there must be another description of rifled artillery with a more simple projectile and rifling, thus doing away with the deep re-entering angles of the Woolwich gun; or the American system, of a large smooth-bore gun, must be followed. But even in the latter instance he would not advise, nor would he desire, cast-iron artillery to be employed.

Mr. J. C. Haddan said he was an advocate of cast-iron guns. In the Armstrong 70-pounder cast-iron gun, the metal was thinner behind the trunnions, and the deficiency was made up with wrought-iron hoops. He believed many hundreds of these guns had been ordered before one was tried, and, as might have been expected, gun after gun burst, and cast iron was in consequence unfairly condemned. No stress should be laid on the failure of the cast-iron guns which burst in the competitive trials, the competitors being confined to two rounds each to ascertain the charge, which was manifestly insufficient. Mr. Britten considered 5 lbs. of powder sufficient, while he adopted a charge of 7 lbs., which was evidently too much. It should be remembered that the trials of cast iron hitherto were made with quick burning powder. The question was, could cast iron be made available when pebble powder was employed? It was not generally known that the bursting of guns was owing to the vents; small cracks formed in the metal round the bush, which gradually extended till the gun burst. He felt confident that might be remedied, and the life of all guns greatly prolonged, by making the end of the vent next the bore trumpet-shaped.

Major Palliser remarked, with regard to the question of lining cast-iron guns with steel and with coiled wrought iron, that he had long been an advocate of the latter plan. He would give from memory some comparative results of the testing of those guns. The first steel-lined gun, a 64-pounder, after firing a considerable number of rounds, had burst with a 26-lb. charge of French powder and 132-lb. shot. Comparing that gun with a cast-iron 32-pounder which he had lined with a coiled wrought-iron tube 2 inches thick, and had tested with increasing charges of English powder, he

remarked that the charge which eventually disabled the gun was 30 lbs. of powder and a 150-lb. shot; and the gun, instead of bursting with violence, merely split the cast-iron casing. The wrought-iron barrel was taken out and put into another bound up cast-iron 32-pounder, and had passed proof satisfactorily. He might observe that there was a great difference in the strength of French and English powders. Yet the steel-lined gun burst with violence with 26½ lbs. of French powder and a 132-lb. shot, while the coil-lined gun only cracked its cast-iron casing with 30 lbs. of English powder and a 150-lb. shot. The charge of powder was so large and long, that the front part of it reached the hole drilled in the gun to receive the fore-sight, where the cast-iron casing had become slight, and, consequently, the casing cracked through that hole.

The next steel-lined gun was a 68-pounder converted into an 8-inch rifled gun, which failed with a 30-lb. charge of powder and 150-lb. shot. That gun he would compare with a 68-pounder, converted at his own expense into an 8-inch rifled gun, by means of a coiled wrought-iron tube 2½ inches thick, and tested also at his own expense. The proof charge was 37½ lbs. of powder and a 180-lb. shot; and 50 rounds of 30 lbs. of powder and 180-lb. shot were fired before the gun was taken out of the proof-cells at Woolwich. It was then removed to Shoeburyness, and was fired for endurance with varying charges. A certain number of rounds were fired with air spaces from 10 inches up to 50 inches in length, and with charges of 22 lbs. of powder. The shot was purposely rammed in the first instance only to within 10 inches of the charge, the next round to within 20 inches, and the others respectively to within 30 inches, 40 inches, and 50 inches from the powder. That severe test did no harm to the gun. The next test was with 180-lb. shell, containing a bursting, charge of 14 lbs., and having holes bored through the base. Five shells were thus fired with 22-lb. charges, and all of them burst inside the gun without doing any harm. The gun then completed an extended endurance test, and was now at the Elswick Ordnance Works, where it was originally made; it was quite uninjured, and remained perfectly serviceable. A 9-inch cast-iron gun, lined with a coiled wrought-iron barrel, fired 4 rounds of 55 lbs. and 500 rounds of 43 lbs. of powder and 250-lb. shot. It cracked the tube at the muzzle, but did not burst it. A Spanish naval officer witnessed that trial, and the Spanish Government were at present converting some 12-ton cast-iron guns in consequence of that officer's report.

The next gun he would refer to was a 32-pounder converted for him by Sir W. Armstrong, by means of a coiled tube 2 inches thick, into a 64-pounder rifled gun. Sir William Armstrong had behaved in the kindest way since he came forward in this matter. He wrote to Sir William in the first instance, stating that he had for many years been making experiments with cast-iron guns, lined with twisted wrought iron and other tubes, and had found nothing satisfactory but the twist barrel, which, when manufactured of a large size, was termed a coiled tube. He admitted it was Sir William Armstrong who had developed the manufacture of coiled tubes on a large scale, and it was with such tubes alone, he considered, that cast-iron guns could, with complete safety, be converted into rifled ordnance. Sir William replied, in the most handsome manner, expressing a readiness to give every assistance in his power, and stating that he entertained no feeling of rivalry whatever. That assistance was subsequently given in the most loyal manner, and the experiments were carried out by Sir William, who placed the entire resources of the Elswick factory at his disposal, and performed the work at the least possible net cost. Sir W. Armstrong subsequently converted twenty 32-pounder cast-iron guns into rifled 64-pounders for the colony of Victoria. One of these guns was rejected at proof at Woolwich for some defects of manufacture, viz., flaws in the powder chamber. The Ordnance Select Committee wanted to get a gun to compare with two wrought-iron 64-pounders, both of which had burst after firing about 2,100 or 2,200 rounds. He put forward the rejected gun for this trial, to prove the fallacy of the then prevalent distrust of circumferential blemishes in coiled iron barrels. This gun had serious faults of that nature in the powder chamber, and he purposely selected for that test a gun believed to be bad, and which was rejected at proof. That gun fired 2,285 rounds, and was perfectly serviceable at the end of the test. The firing was discontinued because the Committee considered further firing a waste of powder and shot. He had burst a great number of guns in experiments, for his own information, and in order to arrive at the truth by a process of elimination. The process was no doubt an expensive one, but the money came out of his own pocket. Moreover, it was necessary, as no theories in gunnery were worth anything unless proved by the practical test of experiment. Notwithstanding the various violent tests to which he had subjected them, no cast-iron gun converted on the plan he had introduced into the service had ever burst with violence. The only gun of this kind which had failed was the 32-pounder converted into a

64-pounder already described, namely, the one of which the casing was cracked, and which did not burst with violence. All the guns which burst were experimental guns, constructed to try various modifications, such as, for instance, steel linings, but no gun converted on the service pattern had ever yet burst. There were already upwards of twelve hundred of these guns in the service, and further numbers were being converted day by day. Some of these guns had now been five years in the service, and no complaint had ever been made of one of them.

Mr. P. M. Parsons observed that Mr. Haddan proposed in his patents to cast the gun on to a tube, or to shrink it on by heating the gun; and Major Palliser had, in the experiments he had made previous to 1860, and which were only with small model guns, also cast the gun on to the tube. There were likewise many others who had proposed or tried the same thing. But there was a wide difference in principle between casting or shrinking a casing on to a tube, and fitting a tube into a gun in the manner he proposed in 1860; and the Ordnance Select Committee, in their report upon it, said that it had not been previously tried. The principle he claimed to have originated, and the Government had admitted it, was fitting a tube of a stronger and more elastic material, such as steel or wrought iron, into a cast-iron gun, in such a manner that the tube would first absorb a large portion of the strain, and in stretching press upon and bring the cast iron into play.

He could not admit that the gun alluded to by Major Palliser, was superior to the 68-pounder converted by him; altogether it did not fire quite so many rounds, and of these only 50 were with 30-lb. charges. Moreover, Major Palliser's gun was vented at the end of the bore, while his was vented according to the service regulation, viz., $\frac{1}{10}$ths the length of the charge from the end, which, it was well known, doubled the strain on the gun. The rifling also in his gun had a quicker twist, and the shot was in consequence delivered with a higher velocity.

Mr. J. A. Longridge thought the Author made a great point of small charges and large bores; but he omitted to remark the necessary consequence of that, which was the low velocity given to the projectile. To obtain a high velocity, the Author said a large bore was required, but owing to the resistance which a large body experienced, the shot must be heavy in proportion to the area of its section to keep up that velocity; and in this case a large charge of powder was necessary. The true remedy was, not to diminish the charge of powder, but to increase the length of the

gun. He was persuaded the present large guns were all too short. It had been well said that the expansive power of the powder had not time to perform its work efficiently.

He could not but think, either from the mode of experimenting or from some other cause, there must be some error in the results given of the initial force of the discharge of the powder. Thus, in Table II., in the case of the 11½-inch 35-ton gun, with 120 lbs. of powder and 700-lb. shot, it was stated the pressure was 46 tons per square inch, whereas, in the 12-inch gun, with the same weight of charge and shot, the pressure was only 27 tons per square inch. He did not believe that by increasing the diameter of the bore ½ inch, the pressure could be reduced from 46 tons down to 27 tons. Then again, from the same Table, it appeared that by increasing the charge of powder 10 lbs. a pressure of 63·7 tons per square inch was obtained, whereas the velocity from that pressure was 16 feet per second less than the velocity with the lower pressure of 46 tons. He believed that was impossible. If there was a pressure of 63·7 tons per square inch in the gun, and the gases followed any reasonable law of expansion, it was evident there must be a higher velocity than 1,348 feet per second. The method he had adopted for a considerable period for ascertaining the probable initial pressure was that of calculating back from the velocity.[1] He had calculated the pressures in a great many guns from data furnished by Captain Noble, and he had prepared the annexed table showing some of the results:—

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[1] The method of calculation was as follows:—

The work done in passing through any small element of the length of the gun, say δ, was equal to the pressure per square inch of area at that point into the length; and if

P = initial pressure,
l = length of charge,
x = distance moved by shot,
$\gamma = 1{\cdot}41$,

this pressure at $x = P\left(\frac{l}{l+x}\right)^{\gamma}$.

Whence, by integration, since the total work done was equal to half the *vis viva*,

$$P = \frac{v^2 W (\gamma - 1)}{2 g l \left\{1 - \left(\frac{l}{l+x}\right)^{\gamma-1}\right\}}.$$

Whence v = velocity in feet per 1″,

$$W = \frac{\text{weight of shot + weight of powder}}{\text{area of shot}} = \phi \text{ in the above table.}$$

$$g = 32{\cdot}3.$$

Bore.	Charge.	Shot.	Velocity.	Pressure.	ϕ.
Inches.	Lbs.	Lbs.	Feet per Sec.	Tons per Sq. In.	
13	70	620	1,220	25·14	5·25
..	60	620	1,136	24·07	5·17
10	60	400	1,290	24·03	5·95
..	55	400	1,227	22·97	5·87
9	43	250	1,340	24·55	4·71
8	30	181	1,363	24·20	4·28
..	20	181	1,165	20·68	4·08
6·3	30	150	1,145	23·11	5·92
..	..	100	1,370	23·89	4·28
..	..	50	1,763	24·37	2·63
..	20	150	1,070	21·47	5·59
..	..	100	1,270	21·35	3·95
..	..	50	1,691	22·59	2·30
..	10	150	931	21·12	5·26
..	..	100	1,136	21·61	3·62
..	..	50	1,560	22·23	2·97
15	100	450	1,543	21·88	3·16

One circumstance he could not account for, but it was persistent in all these experiments—with the lighter shot the initial pressure was greater.

In these calculations he took cognizance of the weight of powder set in motion in the experiments; but he did not take account of the motion of the air before the shot left the gun. He believed it was not necessary to do so, for, up to a velocity of 1,200 feet per second, it had probably no great effect. The best proof of this was the near accordance of actual results with those calculated by the formula.

The Rodman gun, with a 100-lb. charge and 450-lb. shot, gave an initial pressure of 21·88 tons per square inch. If this method of calculation were admitted, it was quite impossible that such a pressure as that could exist in the 35-ton gun; because, if it were so with slow-burning powder, where the greatest pressure accrued at about half the length of the charge, and even supposing no effect due to the pressure before that point, the estimated velocity would be 2,216 feet per second, instead of 1,340 feet. He was therefore convinced that the pressures given in the Table were not to be depended upon. He had seen no experiments in which the velocity given to the shot might not be accounted for by an initial pressure of 25 to 26 tons per square inch, supposing the powder was burnt instantaneously; but as that was not the case, *à fortiori*, the pressure must be something less.

The pressures with R.L.G. powder and with pebble powder,

Table I. in the Paper, showed the great advantage of slow-burning powder, because the maximum pressure was little more than half in one case what it was in the other. The average pressure with pebble powder was in one case 6·3 tons on the square inch, and in the other 5·63 tons; so that no doubt it was a considerable advantage, in reducing the strain on the gun, to have a powder which would burn somewhat slowly. It must, however, be observed that the charge of pebble powder was one-sixth greater than that of R.L.G.

In his opinion a large gun should be constructed with an inner shell, wound round with steel wire, and cased with cast iron. He had no reason to doubt the principle of the wire construction, and he thought there would be a great saving in cost. He had received estimates for two large guns: the first of 24 inches bore, and 140 tons weight, was designed to throw a shot of 1 ton, with a charge of 450 lbs. of powder, with an initial velocity of 1,600 feet per second. The strain on the inner shell during explosion was only 2 tons per square inch, and on the wire 30 tons per square inch. That was the maximum strain with that charge, the initial pressure inside the gun being 27 tons per square inch. The cost of that gun would be £2,500, or somewhat under £20 per ton. The other was a 15-inch gun, 45 tons weight, designed to throw shot of $\frac{1}{2}$ ton, with a charge of 224 lbs. of powder. The initial velocity in this case was 1,569 feet per second, the initial pressure 29 tons, the tensile strain on the inner shell 2 tons, and on the wire 30 tons. The cost of that gun would be £900. He thought that system of construction was worth a trial.

Captain HEATHORN remarked that, on the score of economy, he approved of Mr. Britten's plan for the conversion of ordnance. In the text-book of the construction of rifled ordnance, corrected to January, 1872,[1] it was stated that the 68-pounder 95-cwt. gun was being converted into an 80-pounder gun of 5 tons weight, by partially filling up the gun with a tube, which reduced the bore, necessitated a longer cartridge, and cramped the space for powder-gas expansion. The alteration of the gun cost £250; whilst Mr. Britten converted, at the cost of only 10s. per gun, a like piece of ordnance into a rifled gun, which fired shells of great bursting-charge capacity, each weighing 90 lbs. instead of 80 lbs. This rifling in no way affected the gun's round-shot capabilities. On the contrary, according to a report of the Ordnance Select Committee, it appeared that, in a trial between guns of similar calibre, one a

[1] *Vide* page 144.

smooth bore, and the other rifled on Mr. Britten's plan, "the rifled gun practice made better shooting with the round shot than the smooth bore;" moreover, the results were stated to be decidedly in favour of the rifled gun. With regard to the remark, that Mr. Britten's system was inapplicable to heavier and longer shot, the American projectiles on his system were longer than any used in this country; and the 620-lb. shot of the American 12-inch rifled gun was longer than the 600-lb. English shot of the same calibre.

Mr. Gregory, Past-President, said if a gun had to be constructed to do the greatest amount of damage to armour plates—not point-blank, but at ranges of from 1,000 to 1,500 yards,—he thought about the last material selected would be cast iron; for while cast iron had its uses and its value, still, where a structure had to bear the strain of enormous blows, irregular in their amount, it would be natural to prefer not only the strongest, but the toughest materials obtainable, in which the modern improvements of Armstrong, Whitworth, Fraser, Bessemer and others had given so much assistance. He submitted it might be concluded, from the experience of the Americans, who had employed large cast-iron guns more than the British, that if they did continue the use of those guns in their service, it was not from choice, but rather from financial necessity. That was the only reason he could assume for those guns still being used, after their serious failures, and the official reports made against them.

Many of the circumstances brought forward in the course of the discussion had been presented by those who, from a belief in some particular form or description of invention, might involuntarily have their judgments biassed, and be more ready to adopt proofs of the supposed failure of the Government guns, than they would if they were perfectly independent judges, and if they had access to the mass of information which was only to be found in the records of the Government, whose experiments were much larger and more varied than the experiments of any private individual could be.

He confessed he was rather alarmed by a statement, based upon a Table referring to a certain number of failures said to have occurred in the British guns. His alarm was greater than it otherwise would have been, from the belief that the gallant officer, whose observations he referred to, not only spoke from professional knowledge, but that, being now in the service as a gunnery officer, he had an opportunity of knowing intimately all that had been done and was being done. He was sure, however, the gallant officer would not consider it disrespectful on his part if he men-

tioned that it was about ten years since that officer left the service, and in the interval the most marked advance had been made, and the most varied experience had been obtained, in the manufacture and use of large rifled guns by the Government. He had a Table, apparently the same as that which had been alluded to, giving a statement of a certain number of failures of British guns. The Table was to be found in connection with an article in "The Naval and Military Gazette" of 23rd of March, 1872, obviously written with no friendly feeling towards the Government, and perhaps the so-called facts might have been coloured by partizanship. Out of the thirty-three guns named, as far as he was able to judge, there were only seventeen which had been guns in the service; the remainder were experimental guns, not all of them even of wrought iron, some being of cast iron and some of bronze. The injuries to eleven out of the seventeen guns were so trivial as hardly to be worth notice; the necessary repairs were such as might be indefinitely deferred; and those which required immediate attention were repaired, as stated in the Table, on board ship. Of the remaining six out of these seventeen guns, three appeared to have been injured in the chase by the premature explosion of shells, and three others were similarly damaged by the breaking-up of the projectile in the gun.

Now, the Government did not go on blindly using a particular gun or projectile, without improvement, when improvement might be required. Looking to the fact that so many of the injuries to the guns had arisen either from premature explosion or the breaking-up of the projectiles, he might state, he believed authoritatively, that by a modification in the application of a valuable invention, and by casting only the front of the shot in a chill, its breaking-up in the gun had been prevented. He did not say that premature explosion of shells was always avoidable, but certainly one element of injury to the guns had been removed.

There were two instances of guns having burst violently. One of these he had ascertained was a cast-iron gun; but although that gun did burst, as the Table stated, into seventy-six pieces, it had been treated very severely, and the charge by which it exploded was abnormally heavy. He was informed that it was burst, not at the first round, as stated in the Table, but at the 165th round. The other gun that burst violently was a wrought-iron Woolwich gun; it burst on proof; and Mr. Fraser came to the conclusion that the gun was too weak, and no gun of the same pattern had since been made.

With reference to the four guns of the 'Monarch,' the story of

which must have frightened some of the members, the injury was thus described in the Table. No. 1: "Grooves slightly burred by studs." "Cessation of fire—none;" repaired "on board." No. 2: "Groove slightly burred by studs;" no cessation of fire; repaired "on board." No. 3: the same. No. 4: "Vent damaged—revented." This gun, according to the Table, had fired 243 rounds: no wonder the vent wanted repair. He was not responsible for the accuracy of these particulars, but he took the statement as he found it, and it certainly did not point to serious failure.

As to the actual facts of the working of the Woolwich guns on board ship, he had seen a statement from a gentleman still in the Government service, that during the last two years he had examined officially every gun belonging to all the vessels paid off, or brought into harbour to refit at Portsmouth; amongst others, the guns of the 'Monarch,' as also those of the 'Hercules,' 'Minotaur,' 'Warrior,' 'Lord Warden,' 'Bellerophon,' 'Royal Oak,' and 'Repulse.' In some cases the guns passed more than once under the view of that officer, and the inspection embraced guns of every size. In only one instance had any fracture of the inner barrel been detected, viz., in an 8-inch gun of the 'Royal Oak,' returned from the 'Prince Consort,' of which the inner barrel was fractured near the muzzle, the injury being evidently caused by the bursting of shell in the gun. In several instances the barrels were injured by the breaking up of the projectiles, particularly in the 'Hercules' 10-inch gun; but in no single case was there evidence to show, that any injury or defect was attributable to the method of rifling, or to want of strength in the gun. Many of those guns were stated to have fired a large number of rounds.

He did not mention these facts as being conclusive in favour of the Woolwich gun, for he had not studied the question sufficiently to form a definite opinion. He felt, however, that before any radical change was adopted in guns, made under the skilful supervision of honest and independent men, with a larger amount of experience than any one wedded to a particular plan could have, there should be a careful examination of reliable returns, so as to show by facts whether what had been done was marked by failure or success. He hoped that full particulars with regard to the Woolwich guns might ere long be produced, as the result of the action of an honourable member of the House of Commons, who had given notice of his intention at an early date to propose that Mr. Bashley Britten's system of ordnance should be adopted for the service, and that the present system should be abandoned. He had no doubt

many arguments which had been used in the present discussion would be brought forward, as here, in all good faith, in support of that proposition; but he thought, on the other hand, that the legislature, before coming to a decision, would wait to hear the facts that might be brought forward by the Secretary of State for War.

Lieutenant-Colonel A. Strange said, he had attended the Institution to learn, but he had not been taught. He came expecting to hear a discussion indicating a great advance of knowledge in these matters. He had been wofully disappointed. With the exception of Captain Simpson, who really seemed to speak with a knowledge, not only of facts, which of course were most invaluable things, but also with a knowledge of principles—with that one exception, there had not been, to his mind, any speech that threw a distinct light on the question. Captain Simpson seemed to have grasped certain leading principles, and he had an array of facts such as no other speaker had brought forward. Now, the questions discussed were the old questions of the materials of which guns should be constructed; the disposition of those materials; the relative diameter and length of the bore; the form, size, and weight of the projectile; the character of the rifling, and the quality of the powder. He used to attend discussions on guns eight or ten years ago at the United Service Institution, but for many years he had paid very little attention to the matter; and now he did not hear anything more enlightening than he did then. Further, he felt bound to say more knowledge was shown in the Paper by Mr. Longridge,[1] and the discussion thereon[2] in February, 1860, than on the present occasion. At that time Mr. Bridges Adams ended his remarks in these words: "Meanwhile, the threshold of improvements in artillery was only now reached, and the subject had yet to be exhausted, before it would be safe to rest on the present amount of knowledge."[3] Now the threshold was reached in 1860—not crossed. Since then the threshold had been crossed, but no instruction had been gained, for the light of science had not been brought to bear on the investigations. Indeed the threshold must be recrossed, and another entrance sought. The right form for a gun was no more known now than it was then. Mr. Bashley Britten had bestowed an immense deal of attention on this subject. He had at his own cost entered into lengthy and laborious experiments. He was well known as a conscientious man. It was to be

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., pp. 283–337.
[2] *Ibid.*, pp. 338–460. [3] *Ibid*, p. 433.

expected that the authorities would have been only too glad to receive the aid of such a man ; but to his great surprise he found this was not the case. He was himself in the Government service, and he was not going to say what were the secrets of the prison-house, and how matters were managed in the Government departments : but here was one result. He was far from blaming individuals— far from intending to say that there were men who wished to retard improvements, or who wished to put down one man and set up another. But the departments lacked scientific knowledge, and it was that lack of scientific knowledge which made it difficult for the officials to hold out the hand to those who possessed it. Hence inventors had naturally great difficulty in getting access to the Government. Now, the answer to this would be, " If it is not the fault of the men, it is the fault of the system." He said, " No." It was not the fault of the system : it was because there was no system. It was because in England, with its enormous resources, there was no system by which these resources could be used to the best advantage for the public service. At present there was no scientific organisation in this country : there was no organized body to which scientific questions could be referred. It had been said this question should be submitted to men of the highest experience and knowledge ; but where were the men ? Committees were appointed to discuss these matters, and to decide upon them, who did not possess the confidence of the country. It was notorious that these Committees were selected from amongst a class of most admirable persons, no doubt, but not those best capable of handling the subject. Here there was a Guardsman ; then a few officers of the line ; then a few quasi-scientific men without science, and a few artillerists without knowledge of artillery : and the whole garnished with a sprinkling of lordlings. That was the composition of most of the Committees that had dealt with such questions. It was most suicidal and destructive to the interests of this country, that questions of such importance should be left to people who were not qualified to deal with them.

Captain J. Selwyn, R.N., contended Mr. Bashley Britten had proved that cast iron could be successfully made to fulfil any modern gun requirements. All his trials had conduced to the result that farther experiments were necessary, especially having regard to the enormous stock of existing cast-iron ordnance. Such experiments would have a secondary value, far greater than their primary value, in showing that cast iron, properly placed to resist compression, was more valuable than wrought iron, if it were lined with the steeled surface necessary to resist

and distribute the impact of powder gas. Wrought iron was used at a disadvantage, except where all the strains were tensile. Of this there was evidence in the guns themselves. The bore of an injured gun was wedged open along the inside whenever a fracture occurred, just as if a wedge were driven from the centre of the bore along the walls of the gun; indicating side compression of the material, which could not take place so easily in cast iron. He should be glad to see experiments made—not only with the Britten gun, but with the Rodman gun, and also with the gun of an American named West, who had proved, by hardening the inside and slowly cooling the outside, that a cast-iron gun would bear a strain far beyond what it was likely to be subjected to ordinarily.

Mr. G. H. Phipps remarked that many opinions had been offered on different constructions of guns; but he thought these should have been secondary to the discussion of the leading principle in the Paper, which was, that with a large bore, and with less strain upon the gun, a larger proportional amount of *vis viva* could be obtained for each inch of circumference of the projectile, at the moment of striking the object, than with guns of small bore. With respect to the initial force of fired gunpowder, he was by no means convinced that the manner of proceeding mentioned by Mr. Longridge, namely, by taking the space occupied by the powder and the known velocity of the shot on leaving the gun, afforded the requisite data for arriving at the force. Count Rumford, an eminent authority on this subject, had put the pressure higher than 50 tons on the square inch. Considerable weight should be attached to the observations of Mr. Imray, as to the effect of the inertia of a large mass of material round the breech of a cannon. Although, from the nature of the problem, it seemed almost impossible to arrive at a numerical value of the strength thus obtained; yet, given the thickness of any annulus of the material, say of 1 inch in width, until it was ascertained what was the duration of the small portion of time in which the force was at work tending to burst the annulus, the value of the inertia of the material could evidently not be assessed.

Mr. K. H. Cornish observed, through the Secretary, that it was clearly established that long ranges produced small results; that large guns were more troublesome to work and transport than pieces of moderate sizes; that much powder entailed great waste; that strong powder caused considerable damage to the piece from which it was fired; that cast iron was, if of good quality, and cast in a proper form and manner, adequate to

produce the effect desired for all ordinary purposes; and that it was not proved it would not do for extraordinary purposes quite as well as more costly materials. Though great credit was due to Mr. Britten for pointing out this fact, the true value of cast iron for heavy artillery was demonstrated nearly a hundred years ago by a distinguished French officer, M. le Marquis de Montelambert, the author of a work on fortifications and artillery, entitled "Sur le Fortification Perpendiculaire," printed, under the authority of the Academy of Sciences, by the government of Louis XVI. A Paper on the use of cast iron for artillery was read before the Academy and accepted by a Committee, of which M. de Buffon was a member, which would be a credit to the present age. This Paper was read in 1785, and was republished in the 5th volume of M. de Montelambert's work on fortification. M. de Montelambert's two principle tests of cast iron were colour and specific gravity. If these were right, the piece was sound; if not, it was likely to, and often did, burst.

Vice-Admiral E. P. Halsted remarked, through the Secretary, that twelve years ago a discussion on a similar subject resolved itself into the question, whether Sir W. Armstrong's 'coiled iron,' or Sir J. Whitworth's 'homogeneous steel,' was the better material for the purpose. Meantime both 'Polygroove' and 'Shunt' guns had perished, and their successor, the present 'Woolwich' stud gun, was evidently *in articulo mortis*. The 'coiled iron,' as formed in the Government factory, in continued preference to steel, was the equally fatal element in all; while the Whitworth steel and his polygonal rifling, though scarcely alluded to in the Paper, had gone on progressing under Government disfavour to an extent, apparently, but little known, yet so as to leave little to be desired. Two months since he had witnessed at Manchester the forty-second repetition of an unquestionable proof, that Sir J. Whitworth, in his 'compressed steel'—amounting now to 12-ton masses under the 'squeeze' of 8000-ton presses—had successfully, and permanently, produced a metal which made a gun that could master its charge of gunpowder instead of the charge mastering the gun. To this 'compressed steel,' for guns and projectiles alike, he alone looked for furnishing the Navy for successful iron-clad warfare.

Mr. C. M. Poole, through the Secretary, stated that if Mr. Longridge, when he spoke of integrating between o and l, zero being the starting point of the shot inside a gun, and l the distance of the muzzle of the gun from that point, meant by integration the summation of a finite number of terms, his formula might be

correct; but if he meant the limit of an infinite series, then there must be some mistake. For in this case he must have some function of x to be integrated, which function, Mr. Poole thought, was not yet attained. There was a close analogy between the movement of a piston in its cylinder propelled by the steam, and a shot coming through a gun propelled by the expanding gases of the exploded gunpowder. He had searched in vain for a definite integral, based on correct data, expressing the work done by the steam in a steam cylinder; and he inferred that if a definite integral could not be found to express the work done inside a steam cylinder, where the pressure could be gauged with considerable accuracy at any instant of the stroke, it was hopeless as yet to attempt to discover such a formula for the work done inside a gun, where the behaviour of the gases and of the shot was to a much greater extent a matter of conjecture than the behaviour of steam inside a cylinder.

Mr. Britten, in reply upon the discussion, communicated, through the Secretary, the following remarks:—

In venturing to call in question the soundness of the mechanical principles on which the Woolwich guns were made, the Author was fully sensible of the responsibility he incurred, and of the difficulties he would have to face. In reviewing the debate, he proposed to deal mainly with the remarks of Captain Maitland, Lieutenant Jones, and Colonel Owen, as what he had to state in reply to those officers would be found to answer what had been said by others. To advance this important question it was necessary to trace effects to their causes, and to deal with the principles which governed them.

Captain Maitland said the Woolwich guns were complained of as being "deficient in endurance," as well as "needlessly strong," and this was regarded as an inconsistency. It was admitted in the Paper that, even with the old violent powder, the guns were not liable to burst; and it was nowhere stated that they would not last fairly well when fired with the new powder, which was not so destructive. It was obvious that the question of endurance was distinct from that of structural strength; for if the guns were ten times as strong as they now were, they would not be able, in continuous action, to fire a single shot the more. Their endurance would be at an end when the firing had to cease because the bore required to be re-lined; and this was of greater importance than how often they might be repaired and re-issued. The broad question was whether equally good, or possibly better work, might not be accomplished by dispensing with the employment of un-

necessary violence. The problem was not how to conquer force, but how to guide it to the best advantage. One step in advance had been taken by important improvements in powder, and now it remained to improve the guns. All the ordnance at present being made were only adaptations of old plans to new conditions which ought to render them obsolete. The guns were not designed for the actual work; still it was argued they were perfect as to strength. As evidence of endurance, statistics of several of the 7, 8, and 9-inch muzzle-loaders, which had been tried most, were quoted, showing that even when fired with pebble powder, they had not burst; yet it was contended that, even with so much less to do than formerly, the guns had no strength to spare. It was strange to have to vindicate the strength of wrought-iron ordnance, in opposition to the authorities; but it was evident there was something about the question that required to be explained. The improvements in gunpowder could not be a mere delusion; yet the present instruments for measuring time and pressure, which had been in use some years, had led to no practical result as regarded gun construction. The only reasons advanced for continuing to make guns on the patterns of ten years ago, rather than on the cheaper plan proposed, had reference to the powder. Captain Maitland said, "The pebble powder was new, and not so regular in its action as could be desired; and the guns were still liable to heavy strains occasionally." It was admitted that its actual composition was the same as it always had been; therefore the causes of the irregularities depended on certain accidents. For instance, he said, "The grains were fairly regular oblong or square masses, and as they fell together in the cartridge, they might either leave the desired interstices, or might perchance fit like bricks in a wall. In the latter case the mechanical conditions of regular evolution of gas were not fulfilled." Certainly, if they fitted like bricks, the mass would be more compact, and the combustion not so rapid; consequently the resulting pressure might be less, but could not possibly be more. This would not account for dangerous strains. Another accident which it was said "might cause violent strains," was, that in transport "some of the large grains might get broken up, and fail to afford the desired regularity." It was no doubt possible that a few lumps might get fractured, but it was not probable that this could occur to such an extent as to make any difference to the guns. Pebble powder was both denser and harder than ordinary powder; in fact it was harder than slate, and the lumps could not be broken except by great force. Gunpowder was not usually knocked about violently, because

it recommended itself to careful handling. And even supposing a few pieces did get broken, it was not clear that the consequences would be such as were apprehended. A few years ago, one of the 15-inch cast-iron guns, of the United States, was fired experimentally with service charges, one-fourth of the powder being of the ordinary kind used for muskets, the remainder being pebble, or mammoth powder, as it was there called. Colonel Benton, a distinguished officer of Engineers, who was in command of Washington Arsenal at the time, had stated[1] that this mixture made little difference, either to the gun or to the velocity of the shot, and "would not produce an injurious strain." As another reason for thinking there was no strength to spare in the present guns, Captain Maitland pointed out that, "in the 8-inch guns, the strain on the parts of the bore between the trunnions was about 2 tons per inch greater with pebble powder than with R. L. G." In all the service guns of the present patterns, as well as in the proposed 15-inch gun, there was just as much metal round the bore at the trunnions, as round the powder chamber; and it might be seen by the details of the chronoscope experiments, that at 38 inches from the end of the bore, where the trunnions were, the pressure, when the old powder was used, came down from 30 tons to about 8 tons, and with the new powder, to 10 tons per inch. That the Woolwich rifled guns were subject to great irregularities of pressure must of course be admitted. It was, however, assuming too much to say, that therefore an extravagant employment of costly material was necessary. Indeed, there was reason to believe that cast-iron, on the exterior of the structure, would afford as much strength as wrought-iron, if not greater strength.

Before considering this point, two questions had to be settled, 1°, need there be such strength? And, 2°, need there be any of these irregular pressures? They were abnormal, and were the result of a definite cause; let this be discovered, and it might no longer be necessary to provide against them. First, then, was the new powder so uncertain as to justify the retention of the present designs? It would be seen that the gun No. 208 had done most work of all those mentioned, and this had fired 1,332 rounds. "This gun was used for testing powder, and had consequently to support a great variety of strain. Its bore was originally 7 inches." Now the 8-inch guns of the service patterns weighed 9 tons. This 8-inch gun weighed less than 7 tons. The ordinary maximum thickness of wrought-iron in the 8-inch guns, according to the official text

[1] Rep. Ordnance Committee of the U. S. Senate, 1868. No. 173, p. 113.

book, was $13\frac{3}{4}$ inches; in this gun it was only $11\frac{3}{4}$ inches. It had shown all this endurance as a 180-pounder 8-inch gun, whereas it was only a 7-inch 115-pounder, weakened by being bored out to 8 inches—in fact, it had less metal than any other 115-pounder in the service. The powder tests consisted of the full battering charge, viz., 35 lbs. of powder, and special shot weighing 180 lbs. The shot were turned to fit the bore more accurately than service projectiles, consequently there was less windage, and greater pressure. It was not a rifled gun, and the shot were plain cylinders. If rifled on the Woolwich system, and fired with stud shot, would it afford accurate tests of the powder?

No pebble powder was allowed to find its way into the service without being carefully tested, and approved of in regard to the pressure produced by it.[1] What was the use of this test, if it afforded no guarantee against irregular pressures? The Government specification of quality in all contracts for powder was stringent on this point. Still the makers were able to comply with the specification, and could supply pebble powder in any quantity. But they could not guarantee the quality if they had not so mastered the details of the manufacture as to run no risk of penalties under the specification. The Author had had an opportunity of closely examining the certified results of the trial of 132 different samples of the new pebble or pellet powder, which had been sent to Woolwich from various mills, to be tested in this standard gun. Many of these were merely experimental. Three pressure gauges were used in the gun, so that the trial of the 132 different samples of powder embraced three times 132 independent tests of the pressures; and as the gauges had to detect the difference of quality in each sample, a crucial test was thus afforded as to the accurate working of the instruments. It was satisfactory to find that there were no anomalous results in these records. Within an extremely small margin, all the gauges told the same tale as to the action of each powder, whether it was violent, moderate, or very mild. Of course, none of the powder of the new make in large grains approached the service L. G. and R. L. G., in regard to excessive violence and inefficiency. The pressure from the latter (which was less violent than L. G.), was 30 tons per square inch; and both these were retained for use in the weak cast-iron guns. The

[1] Extract from Government specification in contracts for pebble powder:—"Pressure. The pressure indicated by the compression of copper cylinders adjusted in crushers A, B, and C, should not be greater in any one instance than 20 tons."

highest strain from any of the others was less than 23 tons. Out of the 396 independent measurements of the 132 varieties, there were only 14 instances in which any gauge indicated more than 20 tons pressure. In the great majority of the observations, the pressures varied from 15 to 18 tons. The powder, therefore, could not be the cause of the irregular pressures complained of.

As, then, these irregular pressures were not found in the smooth bore gun, but were confined to rifled guns, the next question was, were they common to all rifled guns, or were they peculiar to those in the British service? To follow this point, brief reference must be made to a little history. Ten years ago, rifled muzzle-loading ordnance having been tried with success in England, its greater simplicity recommended itself to the judgment of practical artillerists, and the complicated Armstrong breech-loading system was condemned. But instead of adopting the system, which had then been extensively tried, and was reported upon favourably, another plan, called the Armstrong shunt system, somehow became adopted. All the early trials of muzzle-loading rifled ordnance were made with cast-iron guns, which were liable to burst if exposed to irregular pressures. The shunt system was tried in these, and they burst; not from excessive charges, nor from a fair trial of strength, for occasionally the guns would fly to pieces after a few rounds, with a moderate weight of shot and little powder. The material of the guns was therefore blamed, just as in this discussion the powder had been blamed for producing irregular strains. Cast-iron was consequently pronounced "weak and uncertain." Such guns might be safely used as smooth bores, with far larger charges of powder (and powder of the most violent kind), than was proved to be necessary to make render thoroughly good rifled guns on the Author's system; but then there were no irregular pressures, or, in other words, the shot could not get jammed in the bore. Up to last year all the new 64-pounders were made on the shunt system. A brief experience, however, showed that wrought-iron shunt guns fared little better than those of cast-iron; many failed, and several burst explosively. The first four 13-inch 600-pounders were shunt guns. They were of the most expensive make, of coiled wrought-iron, costing £4,000, and weighing 23 tons each. In the official text book [1] it was stated, "Of these four, by March 1867, two were ren-

[1] *Vide* "A Text Book of the Construction and Manufacture of the Rifled Ordnance in the British Service." By Captain Stoney, R.A., Assistant-Superintendent Royal Gun Factories, and Lieut. Jones, R.A., Instructor Royal Gun Factories. Printed by order of the Secretary of State for War. Corrected to Jan. 1872. P. 172.

dered unserviceable during experimental practice at Shoeburyness, by splitting their A tubes and some of the coils, and another by splitting its outer coil." A 9-inch shunt gun burst into 42 pieces on one occasion, at the 402nd round. These failures were officially attributed to the shunt rifling.

The shunt projectiles had copper studs, and these went down the grooves easily, but when fired, they were shunted into narrower channels, which they could not pass without either the shot or the gun yielding. Their action in the rifling was described in the text-book.[1] It was this shunt system which destroyed all confidence in cheap rifled guns. Cast-iron shunt guns failed, therefore no other rifled cast-iron guns could be trusted—they must be got rid of for new ones which, under no possible circumstances, could burst. Large numbers of cast-iron guns were now offered for sale. They cost the country about £21 per ton, and, the price of iron being at present high, they sometimes realised nearly £4 10*s.* per ton.

A little attention to certain details would serve to explain the probable cause of the extraordinary pressures which had been referred to. The instant a shot was checked by any obstacle in its course through the bore, the *vis vivâ* of the column of gas moving in one direction was necessarily converted into pressure on the gun. The "grip at the muzzle" in the Armstrong shunt gun was found to produce sufficient check to cause concussion-fuzes, having movable strikers, to explode at the muzzle. Cast-iron guns could not stand being fired in this way, therefore they were rejected. There was no reason why gunpowder should not act as uniformly in rifled guns as in smooth-bores, unless the rifling and the projectiles were designed on unscientific principles. A rifle-shot had to perform in a gun the functions of a screw; and the power to turn a screw working properly was definite and constant. If it could not follow the thread it worked in, but overrode the sides, it became locked. In such a case the utmost resistance it could offer to any advance depended on the strength of the thread; but it could, of course, offer no more resistance than was sufficient to strip the thread and leave it free. In all systems of rifled ordnance, when the screw was represented by studs or ribbed projections of hard or rigid material on the shot, which necessarily had to fit loosely in the gun so as to load easily, unequal action on the bore must occur; and when that took place it was accompanied by as much excess of strain as was

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[1] *Vide* "A Text Book of Rifled Ordnance." P. 126.

sufficient to overcome the obstacle. All the cast-iron rifled guns which had been tried with rigid studs or projections, whether on the shunt, the French, or any other plan, failed, because they could not resist the pressures produced in overcoming the strength of the material of the screw whenever the thread got out of its course. When, however, the rifling action was on soft metal, such as lead, pewter, or other similar alloy, cast-iron rifled guns had succeeded perfectly. This was not only the case in all the English service guns rifled by the Author, and tried for nine years at Shoeburyness and at Woolwich, but also in thousands of cast-iron guns of moderate size used in actual war in other countries, even when doing as much work in proportion to their weight as any wrought-iron guns. Had they been subjected to these high accidental pressures, they must have burst like the cast-iron shunt and French guns; but they did not burst. Whenever cast-iron rifled guns had failed, as, for instance, the large American Parrott guns, it was simply the result of overloading, and of the employment of violent power. The cast-iron Parrott 100-pounders, 150-pounders, and 250-pounders were considerably lighter and thinner than English wrought-iron rifled guns of the same calibres. Lead or other such substance, under the power of gunpowder, would yield like plastic clay, and adapt itself to its work; in fact, giving way all the time the work was being done, and yet doing all that was required. The broad threads or lands of the soft-metal might be partly sheared away; but in shearing the soft metal, the rifling impressed on the shot the desired motion. There was an erroneous idea that large shot could not be made to spin properly unless hard material was used. In the 10-inch, 11-inch, and even 14-inch breech-loaders of Germany and Russia, the rifling action was produced by lead; and these guns shot with precision. The latter gun had fired lead-coated shot of 990 lbs. weight, with 187 lbs. of powder[1] yielding a punching-power of 311 foot-tons, or nearly one-third more than had ever been accomplished in this country. The projectiles for breechloaders had bands of lead round them, which were compressed. In muzzle-loading guns the soft metal at the base of the shot was expanded into the rifling. So far as it had yet been tried, this plan appeared to be as successful in large guns as in smaller ones: the expanded base had merely to steer the shot round, like the rudder of a ship. In the case of the 10-inch 250-pounder, and the 12-inch 620-pounder cast-iron American rifled guns, it did all

[1] Professional Papers of Corps of Engineers U. S. Army." No. 21. 1871.

that was needed.[1] There was, however, one matter of detail which was essential, and must be pointed out. To produce the rifling action with soft metal, the grooves must have more or less rectangular sides. In the Woolwich rifling the sides of the grooves were curved. It was important to consider the different mechanical effect in the action of the rifling thus involved. The amount of friction on the thread of a screw depended on the inclination of its sides to the plane of rotation. If the sides were rectangular there was a minimum of resistance or friction, because the force to turn the screw fell tangentially, or in a line with the course of motion to be given. In this case the sides formed a simple inclined plane. But if the sides, instead of being rectangular, were sloped, they then exerted a force which might be resolved into two —one tending to turn the shot round, the other directed radially, jamming the shot, and so increasing enormously the friction which resisted its progress; or, in other words, the screw shot became a wedge exerting lateral force. The more the sides were sloped, so much the longer, finer, and more powerful was the wedge; while the force to turn the shot was diminished. The tendency, therefore, in a rifle shot to tighten itself in the bore, and either to become crushed or to burst the gun, depended on the incline of the guiding sides of the grooves.

The Woolwich rifling was adopted as an improvement on the French system. The only important difference was, that what was termed the centering principle was introduced. The French grooves were flat at the bottom, and the sides angular; but this was altered so that the power to spin the shot should fall obliquely. The form of the Woolwich grooves was described in the official treatise on "Ammunition."[2] The centering was attempted to be produced by interposing an incline to the shot's progress, and compelling the shot to strike the gun and override the sides of the screw. In passing out, "the body of the shot never being intended to come into contact with the bore," the whole squeeze was thrown upon the studs, which had to be made of hard gun metal. These studs were let into holes bored to a depth of ·45 inch, leaving in the walls of an ordinary 10-inch

[1] Extract from General Gillmore's Evidence before Ordnance Committee, 1869, (p. 52) in reference to the 620-pounder 12-inch cast-iron rifled guns, tried against iron targets, Sept. 1866, when he was present. "*Q.* Did the sabot metal take the grooves well?—*A.* Very well, indeed. *Q.* And did the firing exhibit accuracy?—*A.* Yes, sir." "The firing was accurate and satisfactory."

[2] *Vide* "Ammunition: Part II. Ammunition for Rifled Ordnance." Printed by order of the Secretary of State for War. P. 57.

common shell, such as recently burst in one of the guns of the 'Hercules,' the thickness of about 1 inch. A minute difference, therefore, in the gauge of the projectiles, or in the shape of the surface of the studs, would give rise to a variable resistance in the shot, because it would cause the studs to impinge on a different point in the varying curvature of the sides of the rifling, forming the incline of opposition. The amount of friction on the studs, in the act of riding up the incline to wedge the projectile into the centre of the bore, also depended on the smoothness of the surfaces brought into contact. It was well known that the effect of the enormous charges now used was to destroy the surface very quickly, and to erode the bore, especially in the grooves. Those who had seen the inside of a Woolwich gun, which had done much work, would know that, for from 12 to 24 inches from the cartridge, the bore sometimes became as rough as the bark of a moderate-sized elm tree; and it was up such a surface that the hard studs had to slide. If the rifling acted uniformly on the gun, the pressures would vary constantly with the *vis viva* imparted to the shot; but in nearly all cases when extraordinary pressures were detected, less *vis viva*, instead of more, was acquired by the projectiles. Remarkable instances of this were recorded in the trial of the "Woolwich Infant," and had been commented on.[1] There was, however, no need for surprise, when it was remembered that the 700-lb. shot was larger and heavier than any other shot previously used, and that with an enormous pressure behind it, it had to be forced up both a longer and a sharper hill; for the rifling in this gun had considerably more twist than any other in the service. The liability of the studs to get jammed was necessarily increased under such circumstances, and then they could only be released by the pressure gathering behind them. The velocity of the shot might therefore be expected to be less while the strain was greater. There could be no doubt that the pressure on a gun must, in all cases, be in proportion to the resistance of the shot. But the resistance of a Woolwich shot was not merely its inertia; it included also the power requisite to crush and grind away so much hard gun metal, which often pushed itself in the way of the shot's progress.

The irregular action upon the studs was practically shown by

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[1] Some examples will be found in the table of measurements made in the 10-inch experimental gun at Woolwich, when bored out to 11 inches. *Vide* Note appended to this reply.

the unequal wear they frequently sustained. When all went well, the studs of recovered shot were only moderately compressed and burnished; at other times the compression was considerably greater; and frequently, even when there had been no increase of charge, the studs were found to have been jammed and ground away to a depth of one-tenth of an inch or more, affording unmistakable evidence of the violence with which they had been pressed against the bore, and of the force of the charge thus thrown upon the gun. When the Lancaster oval bore was first used, it was found indispensable to make the shells of wrought iron, in order to resist the crushing action they sustained, from having to ride up the curved incline on two narrow opposite points. Latterly this projectile had been improved, by enlarging the bearing surface on which the rifling acted. Although the projectile was thus rendered less liable to be crushed in, the sides of the gun were just as liable to be pressed outwards, because the rifling not only served to turn the shot but also tended to stop it. A common wood screw illustrated the action. The sides of the thread were purposely curved that they might act like a wedge, and thrust aside the opposing material.

Alluding to the comments in the Paper on the 35-ton gun, Captain Maitland admitted that it was not a success, but added that it was "made to order." This gun was, in fact, nothing more than a reproduction on a larger scale of what were considered to be the best points of all the other Woolwich guns. It was true that its length and maximum weight were limited by the size of the turret which it was intended to occupy, but how the weapon should be formed (1), what should be its calibre—on which depended its capability of burning powder—and (2) what should be its charge, and the weight of its projectile—on which depended its capability of employing the powder when ignited—these questions were left to the judgment of those who made the gun, on whose technical knowledge the War Office relied.[1] The gun, when finished, represented the deliberate views of its authors. There could be no two opinions about the admirable workmanship these guns displayed; nevertheless, as engines or instruments, designed according to definite rules of art or scientific economy, the Author

[1] *Vide* in "Parliamentary Return of Report of the Ordnance Council on the proposed 35-ton Gun competition. No. 308, 27 June, 1870." "Mem. sent to Royal Gun Factory from War Office" (p. 23). "Specification of Gun by Superintendent R.G.F.," p. 24. Also Col. Campbell's Evidence before Council—Questions 109 to 127, p. 11.

did not hesitate to denounce them as failures,—like those Eastern brass guns which were kept as curiosities in the Arsenal, and which were made on the same idea, that the power of a gun depended upon its strength and thickness. It was said that the design of the 35-ton gun was now being improved upon. Wrought-iron weapons of 36 tons were in course of construction.[1] The calibre was to be the same (12 inches), and they were to fire the same projectiles (700 lbs.); but the length of the bore was to be increased about 3 feet, in order that the full charge of 120 lbs. of powder might be able to catch fire, which it did not in the present shorter guns. The gain in velocity to be looked for from this was scarcely likely to exceed 30 or 40 feet per second; and, in producing this, the gun must become subject, like its predecessors, to occasional irregularities of 30 or 40 tons per square inch additional strain. It was stated to be an accidental strain of this amount which cracked the tube of the "Woolwich Infant," when the pressure measured 66 tons per inch. This could hardly have been caused by the gun being too short; nor was it likely to be prevented by the bore being made longer.

In reference to the argument against the proposal to employ cast iron for the exterior of ordnance, viz., that "it was as reasonable to employ cast iron for boilers as for guns," it might be remarked that when Engineers had only to provide against the effects of pressure, as in large hydraulic presses, they preferred cast iron because it was cheaper, and strong enough, although occasionally worked at a hundred times greater strain than had to be borne by any wrought-iron boiler. It might fairly be said, that it would be just as reasonable to make every part of a gun, outside as well as inside, of wrought iron, as it would be to make large steam engines wholly of that material. The cylinders and subordinate parts might be stronger for it, but the engines would be bad, because, in their construction, the first principle of all science—economy—would be outraged.

The Author had carefully noted Lieutenant Jones' observations, but found nothing in the Paper which required either correction or modification. The service charge for the American 15-inch gun was said to be 50 lbs., instead of 100 lbs., but the authority for the latter statement was Colonel Benton,[2] a distinguished

[1] Descriptive article in the 'Daily News,' May 11, 1872.

[2] Col. Benton's Evidence before U. S. Ordnance Select Committee, Jan. 9, 1868. Rep. Com., No. 173, p. 112.

American ordnance officer. The extracts quoted from the American report on ordnance were from the general statements made by the civilians who formed the Committee; and there was the clearest evidence in the general tone of the report,[1] that the minds of the Committee were strongly prepossessed against the ordnance officials. Not one of the members of the Committee appeared to have been educated either as a military or a naval man; and none were distinguished for scientific attainments specially fitting them for dealing with difficult and strictly technical questions. But their remarks were quoted, and the facts which this report contained, coming from official records, and certified by officers of the highest rank, both in the army and the navy, were ignored. The facts brought forward in the Paper were from the reports of such men as General Rodman, General Gillmore, General Ramsay, Admiral Dahlgren, Commodore Hitchcock, and Commodore Hunt; men who had severally acquired experience in the field or in the factory, and whose veracity was not to be impugned. The impression which Lieutenant Jones' quotations conveyed was, that American ordnance generally had been found to be a failure. But it was only the large guns which had failed, and the reason of this had been already explained. All the smaller ones succeeded perfectly, including the rifled service guns. Only one Parrott gun of less size than the 100-pounder, out of some thousands, showed any want of endurance in service. One 30-pounder blew its muzzle off at the 401st round, but without doing any mischief, and it was afterwards able to be used.

The operations against Charleston, which had been referred to, extended over eight or nine months. This was an affair of great magnitude, and was really the first trial of any heavy rifled guns in actual war. It was true that forty-five men were injured by five of the guns which burst; but these were the only casualties of the kind during the whole of the war. Some idea might be gathered of the extended trial these large cast-iron rifled guns had had in service, from the recorded number of rounds fired by sixty of them, all but three of which were 100-pounders or upwards. These sixty guns fired 31,300 rounds[2] before they failed—an average endurance of 520 rounds. Besides these sixty, many hundreds like them were extensively used, but the number of times they were fired was not known. The sixty guns included all in the official list of which the number of rounds fired was stated.

[1] Page 4 of Report, 1869 (Rep. Com. No. 266).

[2] "List of Guns burst and disabled in Service," Report, 1869, p. 211.

General Gillmore, who commanded 10,000 men at Charleston, stated in his evidence before the Committee,[1] "We lost no men by the bursting of guns. Do not think we lost a single life by it;" and he also said, "I do not want a better small gun than Parrott's smaller guns." From one of these he fired 4,600 rounds into Charleston, 7,000 yards off. Commodore Hitchcock was asked by the Committee whether he thought the 100-pounder cast-iron rifled gun was safe with its service charge, which made it more powerful than the 100-pounder Armstrong gun of the same weight. His answer was,[2] "I ought to think so, sir, when I have seen 20,000 or 30,000 rounds fired with them. I simply base my opinion on that." These guns were, doubtless, ill-constructed, and the large ones failed from being taxed too severely; but, nevertheless, they did not deserve to be spoken of with contempt. It must be remembered that they were used too soon after being cast, and that the powder employed was of a violent kind; not so extremely violent as the English L.G. of that period, but just about the same in quality as the R.L.G., with which all English wrought-iron heavy rifled guns also failed in endurance. The American "cannon" powder, when tested in an 8-inch smooth-bored gun, with 10-lb. charges and solid round shot, showed a pressure of 18 tons per inch, giving a velocity of 1,225 feet.[3] But since then pebble powder had been introduced; and larger charges now produced higher velocities with less than half the pressure.

However lightly the cast-iron American ordnance might be esteemed, it was by no means certain that, weight for weight, English weapons would be more effective. If the American Government retained cast-iron guns in their service (and there seemed no probability of their doing otherwise, after what had been stated by Captain Simpson), it was because they had tried them, and really knew what they were. The use of the cheap material was rejected in England, because no fair trial had been made with it.

Some trouble had been taken by Lieutenant Jones to check the Author's estimate of the power that might be expected from the proposed 15-inch rifled gun, and according to these calculations the figures given in the Paper were too favourable. This was unim-

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[1] Report, 1869, p. 43.

[2] Report, 1869, p. 23.

[3] Evidence of Col. Laidley, Inspector of Powder at Frankfort Arsenal, American Ordnance Committee, 1869, p. 29.—(N.B.—The charge of L.G. powder used in English 8-inch guns is 16 lbs., and the velocity of solid shot is nearly 1,600 feet. The pressure has not been measured.)

portant, because, if a few pounds more powder were required to yield the velocity stated, they could be used, as it was explained that the charge was not limited to the quantity mentioned by the strength of the gun, but only by its weight to check recoil. The Author could not agree with the remarks as to the probable effect of the proposed charge. It might be true in the case of the 10-inch Woolwich gun, when firing shot of increasing weight with the same charge, that the velocity "varied with the square roots of the shot." If so, it was merely an accidental circumstance in that particular experiment; but no general law could be deduced from that applicable to all guns, irrespective of the conditions under which the charge acted. It was impossible to compare the work of constant charges in guns of unequal length: and the question of more or less windage, and consequent escape of gas, was an important element. This 15-inch gun was designed as a low-pressure engine working with full expansion; and it was compared with another which worked with extremely high pressure and very little expansion.

Supposing the 15-inch rifled gun and the Woolwich 10-inch gun were both fired with equal charges and weight of projectile—say, 70 lbs. powder and 1,200-lb. shot, which was what the 10-inch gun really fired in the experiment reasoned from—the effect of the charge in each would certainly vary with the following conditions. The weight of the 10-inch 1,200-lb. shot in proportion to its area presented to the charge, was $15\frac{1}{4}$ lbs per square inch; while that of the other was $6\frac{3}{4}$ lbs. In the 10-inch bore the pressure of the 70-lb. charge acted over an area in the shot of $78\frac{1}{2}$ square inches; but in the 15-inch bore it acted upon nearly 174 square inches. In the small bore the charge expanded 5·8 times, and urged the shot with a stroke of 10 feet; in the large gun there would be 17 expansions of the same charge, instead of 5·8, and there would be a 5 feet longer stroke. Again, the Author's calculations of the probable velocity from the charge proposed (about 90 lbs.), were based on the assumption of expanding shot being used in the large gun, while in the 10-inch gun stud-shot were employed. In the former case little or no escape of gas could take place; in the latter the ring of windage represented an open area equal to $\frac{3}{4}$ of a square inch, through which the gas, in a state of enormous compression, was free to pass without acting on the projectile at all. The Author's estimate was founded on known results obtained from the 12-inch American rifle, firing expanding shot of 620 lbs., under conditions fairly approximating to those of the proposed

gun;[1] and the probability was that greater velocity would be obtained than was assumed.

The Author would now advert to Colonel Owen's arguments. It was evident that officer, as well as others, had been misled by the official account of the trial, in 1863, of expanding projectiles in the wrought-iron 7-inch gun, in competition with the French, the shunt, and other rifled guns. An idea prevailed, as the result of this trial, that expanding shot were not adapted for powerful guns. It was true they failed in the gun then used; but for this neither the Author nor the system was to blame. The trial was made by the Ordnance Select Committee, who took the matter out of the inventor's control, and experimented in a manner that he at the time wholly disapproved of. In a letter to the War Office, dated 7th May, 1862, he laid before the authorities a proposal for a gun such as he had been informed, during an interview with several of the Lords of the Admiralty at Whitehall, would be suitable for navy broadside armament. The weapon suggested was to be of wrought iron, 10 feet long in the bore, to weigh about 6½ tons, and to have a calibre of 9 inches, so as to fire projectiles of about 170 lbs., with 17-lb. charges of the powder then in use. Instead of sanctioning this, the authorities ordered the expanding system to be tried in a gun of the same weight, but of only 7 inches calibre. In another letter, dated 22nd July, 1863, the Author pointed out his reasons for preferring the larger calibre, and renewed his application for a 9-inch gun, but without success. The 7-inch gun was tried; it was fired with expanding shot of 110 lbs., and charges of 22 lbs. of the violent R. L. G. powder. The expanding shot rendered this charge much more powerful than the same quantity of powder in the other guns firing rigid shot with windage. This was proved by the higher initial velocity. Both gun and shot consequently were subjected to an enormous pressure, probably nearly three times as much as would have arisen in the suggested 9-inch gun. The effect of this excessive pressure upon the lead was, not to detach its fastening on the shot or to blow it off, but the soft metal was scoured away by the gas, just as the gas was afterwards found to scour away the surface of the

[1] The average velocity in 75 rounds of 620-lb. shot, with 50 lbs. powder, in the American 12-inch cast-iron gun, was 1,139 feet.—(Report of the Chief of Ordnance, War Department, for 1868. Report, 1869, p. 164). This gun was 30 inches shorter than the proposed 15-inch rifled gun.

iron or steel bore when stud shot were used. Finding the authorities would not carry out the proposal in the only way he felt it could possibly succeed, the Author withdrew from the competition. Had the Author's proposed 9-inch gun been tried, there could be no doubt the system would have succeeded, for hundreds of guns as large, and much larger, on precisely the same principle, had been found in America to answer admirably. They had been tested for accuracy in comparison with Whitworth 12-pounder guns, which bore the palm when tried against the best rifle in England, and at 2,000 yards they made just as accurate practice. It might be proved that the 9-inch gun would have been a far better design than the massive small-bore 7-inch 7-ton gun which was adopted.

This 7-inch gun (the origin of the Woolwich system) was designed to be strong enough to fire with safety as much powder as could be ignited in it, while the projectile was to be as long as possible. Its power of burning powder was of course limited by the total capacity of the bore; while the length and weight of the shot were limited by the power of the rifling to produce the rotation requisite for maintaining the stability of the shot's axis during flight. The cardinal points, therefore, were extreme charges and high velocities. The Author's 9-inch gun was on the principle of moderate charges and heavy shot. It was said "the object kept steadily in view by the authorities was to get the highest possible velocity out of a gun." Now high velocity was incompatible with great weight in the projectile, for the former must decrease as the latter increased; but it had become an axiom at Woolwich that "the striking effect of a projectile depends more on its velocity than on its weight."[1]

The Author's advocacy of low charges, in comparison with the shot's weight, was attributed to the exigencies of the expanding projectiles; but there was a better reason which, apparently, had not been appreciated. Colonel Owen seemed to be on the track when he said "he had always been in favour of a large rather than a small calibre." With a large calibre, and heavy charges, the shot must be light, or the gun would recoil too much. In this case the gun would produce high velocities like a smooth bore, but it would only be a racking gun, such as was strongly deprecated. If, on the other hand, heavy shot were used, and only such charges as the weight of the gun allowed, high velocities must be abandoned, and then the result would be the Author's plan.

[1] *Vide* "A Text Book of Rifled Ordnance." P. 13.

As there had been so much misconception of the Author's views, he had tabulated the figures on which his plan was based. As regarded the 15-inch rifled gun, the question was, whether a large-bore, low-pressure, full-expansion gun, capable of projecting 1,000-lb. or 1,200-lb. shot with a moderate velocity, was not a better weapon than the present high-pressure 700-pounder, which commanded higher velocity and concentrated its blow on a smaller area. He joined issue, therefore, with the statements of Colonel Owen, that "high velocities were most desirable, as they gave longer ranges, more accurate practice, and greater striking power than low velocities, and in some circumstances, such as firing at iron-plated vessels, were indispensable." "Heavy projectiles and low velocities was the racking plan, which had been long ago exploded."

The Author assumed that the respective values of weight and velocity, in the composition of projectile force, were fairly expressed in the formula by which *vis viva* was calculated in the authorised gunnery tables. If it were not so, those tables were delusive. He had then a right to employ either more or less velocity, or more or less weight, as he thought best. He elected greater weight for stated reasons; but in doing so he was aware that he entailed upon himself, in one respect, more work, because, in order to get command of greater weight in the projectiles, they must be larger, and consequently would have bigger holes to make in effecting penetration, whether in iron or in air. The problem to be demonstrated therefore, was, whether, by a more economic employment of the forces brought into play, he could gain sufficient increase of power to perform this greater amount of work. If holes only as deep could be made with the big shot as with smaller ones, a valuable result was achieved; because a larger hole represented more work done, which, though of a different character, might in many cases be as valuable, or possibly more valuable, than mere depth of penetration. It had also to be borne in mind, that something besides initial energy had to be considered. The Author had therefore estimated what both the striking power and the punching power of the proposed 15-inch gun would be at a range of 2,000 yards, which was a fair fighting distance. He took it to be admitted that the moderate velocities of 1,130 or 1,140 feet per second might be imparted to such projectiles, for whatever charge or strength of gun was needed for this, it could be found. The first point, then, was to ascertain what the effect of the resistance of the air would be on the 1,200-lb. shot started at a speed of 1,130 feet. It was evident that the opposition of the

atmosphere to any projectile must depend, not only on the amount of the actual displacement of the air, and therefore on the shot's size, but also on the amount of the compression of the air, and therefore on the shot's speed. The effect produced by the opposition of the air in reducing velocity would be in proportion to the mass of the projectile in which the *vis viva* was stored; therefore the "carrying power," or conservation power, of a shot must be regarded; and this would approximate to the weight of the shot divided by its sectional area. Careful calculations and measurements had enabled the authorities to compile reliable tables[1] of the velocity and energy remaining in service projectiles after traversing any distance up to 4,000 yards. By finding from these tables what the loss of velocity in service shot was, when travelling at the same speed as the proposed large shot would start with (allowance being made for the respective carrying power of each), it was possible to determine how much velocity the latter would be likely to lose in the same distance.

TABLE showing the Loss of VELOCITY in RIFLE PROJECTILES, of various weights and dimensions, when traversing 2,000 yards, the initial speed being indicated.

PROJECTILE.	Carrying Power of Projectile. Weight ÷ Area of Section.	Velocity at stated Ranges (about 1,140 feet per second), from the Official Tables of Remaining Velocities.	Loss of Velocity in 2,000 yards.
SERVICE GUNS.		At 1,600 yds. Velocity 1,139 ft.	
		,, 3,600 ,, ,, 1,002 ,,	
535-pr. 11-inch	5·7 lbs.		137 ft. per sec.
		,, 1,800 ,, ,, 1,122 ,,	
		,, 3,800 ,, ,, 994 ,,	
			128 ,, ,,
600 ,, 12 ,,	5·3 ,,	,, 1,400 ,, ,, 1,137 ,,	
		,, 3,400 ,, ,, 993 ,,	
			144 ,, ,,
400 ,, 10 ,,	5·1 ,,	,, 1,800 ,, ,, 1,138 ,,	
		,, 3,800 ,, ,, 992 ,,	
			146 ,, ,,
250 ,, 9 ,,	3·9 ,,	,, 1,600 ,, ,, 1,147 ,,	
		,, 3,600 ,, ,, 966 ,,	
			181 ,, ,,
		,, 1,600 ,, ,, 1,141 ,,	
		,, 3,600 ,, ,, 934 ,,	
115 ,, 7 ,,	3·0 ,,		207 ,, ,,
		,, 1,200 ,, ,, 1,217 ,,	
		,, 3,200 ,, ,, 953 ,,	
			259 ,, ,,

[1] *Vide* "A Text Book of Rifled Ordnance," p. 194.

TABLE showing the Loss of VELOCITY in RIFLE PROJECTILES, of various weights and dimensions, &c.—*continued.*

PROJECTILE.	Carrying Power of Projectile. Weight ÷ Area of Section.	Velocity at stated Ranges (about 1,140 feet per second), from the Official Tables of Remaining Velocties.			Loss of Velocity in 2,000 yards.
PROPOSED GUNS.		Estimated.			
1,200 pr. 15 inch	6·79 lbs.	At muzzle „ 2,000 yards	„ „	1,130 „ 1,014 „	116 ft. per sec.
1,000 „ 15 „	5·66 „	„ muzzle „ 2,000 yards	„ „	1,140 „ 1,000 „	140 „ „
200 „ 9 „	3·2 „	„ muzzle „ 2,000 yards	„ „	1,220 „ 965 „	255 „ „

The function which the Author had ventured to designate as "carrying power" could be distinctly traced in these figures. In the instances of the 12, 11, and 10-inch service shot, when travelling with the same velocity impressed, they each lost speed in the inverse proportion of their weight to their sectional area. In the 9 and 7-inch shot the difference was very striking.

The probable loss of velocity being so determined, there was no difficulty in comparing the actual power remaining in the large shot and that in the service projectiles at 2,000 yards from the gun.

The 9-inch 200-pounder wrought-iron "large-bore" rifled gun, proposed by the Author in 1862, had been inserted in the tables, that it might be compared with the "small-bore" 115-pounder of the same weight, which was adopted instead of it.

TABLE showing the REMAINING ENERGY and VELOCITY in the following PROJECTILES at 2,000 yards from the Gun.[1]

GUNS.	Charge.	Carrying Power. Weight of Shot to Area.	Energy and Velocity at the Muzzle and at 2,000 Yards.			Loss of Energy in 2,000 yards.	Punching Power remaining at 2,000 yards from Gun.
			Distance.	Velocity.	Energy.		
	lbs.	lbs.		ft. pr. sec.	foot-tons.	foot-tons.	foot-tons.
SERVICE GUNS.							
700-pr. 12-inch .	110	6·2	Initial . .	1,272	7,863		
			2,000 yds.	1,100[2]	5,880		
						1,983	157
600 „ 12 „ .	85	5·3	Initial . .	1,300	7,030		
			2,000 yds.	1,085	4,890		
						2,140	131
535 „ 11 „ .	85	5·7	Initial . .	1,315	6,415		
			2,000 yds.	1,106	4,540		
						1,875	132
400 „ 10 „ .	70	5·1	Initial . .	1,364	5,160		
			2,000 yds.	1,118	3,470		
						1,690	111·2
250 „ 9 „ .	50	3·9	Initial . .	1,420	3,496		
			2,000 yds.	1,097	2,086		
						1,410	74.4
115 „ 7 „ .	30	3·0	Initial . .	1,525	1,855		
			2,000 yds.	1,078	927		
						928	42·6
PROPOSED GUNS.							
1,200-pr. 15-inch	90	6.79	Initial . .	1,130	10,638		
			2,000 yds.	1,014	8,566		
						2,072	182
1,000 „ 15 „	..	5·66	Initial . .	1,140	9,023		
			2,000 yds.	1,000	6,943		
						2,080	148
200 „ 9 „	20	3·2	Initial . .	1,220	2,063		
			2,000 yds.	965	1,291		
						772	45

[1] The figures relating to British Service Rifled Guns were taken from the official "Text Book of Rifled Ordnance," published by the War Office, 1872, p. 194.

[2] The remaining velocity of the 700-pounder was not stated in the official tables. The loss in 2,000 yards was here estimated at 172 feet, which was 37 feet less than the 11-inch 535-pounder lost in the same distance.

From this Table it appeared that, although the 15-inch shot displaced more air than the 12-inch 700-pounder in its immediate passage, still it would not lose so great a proportion of its power. Travelling more slowly, the air had a longer time to get out of its way; and its greater relative weight rendered it better able to cope with the opposition, for the same reason that a 68-pounder round

shot, starting with less velocity, had a longer range, and would effect greater penetration than a 32-pounder.

In order to present the subject in a still clearer light, the following comparison was offered between examples of the Woolwich high-pressure system and the low-pressure full-expansion principle advocated by the Author.

TABLE of RIFLED GUNS on the LOW-PRESSURE, Full-Expansion principle, proposed by MR. BASHLEY BRITTEN, compared with HIGH-PRESSURE WOOLWICH RIFLED GUNS.

General Details.	Very Large Size.		Medium Size.	
	Woolwich 35-Ton 700-Pr. Bore, 12 Inches. Made, 1871.	Britten's 35 to 40-Ton 1,200-Pr. Bore, 15 Inches. Proposed, 1872.	Woolwich 6¼-Ton 115-Pr. Bore, 7 Inches. Adopted, 1863–4.	Britten's 6¼-Ton 200-Pr. Bore, 9 Inches. Proposed, 1862.
Charge—pebble powder	110 lbs.	881bs. (about)	30 lbs.	20 lbs.
Projectile—shot or shell	700 „	1200 lbs.	115 „	200 „
Length of bore	163 inches	192 inches	126 inches	126 inches.
Area of bore	113·1 sq. in.	176·7 sq. in.	38·4 sq. in.	63·6 sq. in.
Length of cartridge	27·5 inches	14 inches	22 inches	9 inches.
No. of expansions of charge in bore	5·9	13·7	5·7	14
Carrying power of projectile, *i. e.*, weight ÷ area of section	6·2 lbs.	6·79 lbs.	3 lbs.	3·2 lbs.
Pressure on guns pr. sq. in.	18 to 20 tons	13 to 15 tons	13 to 15 tons	10 to 12 tons
Initial velocity	1272 ft. pr. sec.	1130 ft. pr. sec.	1525 ft. pr. sec.	1220 ft. pr. sec.
Velocity at 2,000 yards	1100 „	1014 „	1078 „	965 „
Loss of velocity	172 „	116 „	447 „	255 „
Initial energy	7863 ft.-tons	10638 ft.-tons	1855 ft.-tons	2063 ft.-tons.
Energy at 2,000 yards.	5880 „	8566 „	927 „	1291 „
Energy per inch of shot's circumference at muzzle	210 „	226 „	85·3 „	73·5 „
Ditto at 2,000 yards	157 „	182 „	42·6 „	45 „
DIFFERENCES.				
Greater energy at muzzle	.. ..	35·3 per cent.	.. ..	11·2 per cent.
Ditto at 2,000 yards	.. ..	45 „	.. ..	33·7 „
Greater energy per inch of shot's circumference at muzzle	.. ..	7·6 „	16 per cent.	.. ..
Ditto at 2,000 yards	.. ..	18·3 „	.. ..	5·6 per cent.

In this inference, as to the power of the respective guns, the only assumptions were the initial velocities of the large heavy shot. That these were not too high must be admitted, from their being founded on a low estimate of the velocities obtained in other guns under equal or similar conditions. The initial velocities being allowed, all the other figures were arrived at by calculation. Briefly,

then, the advantage of the large over the small calibre might be thus summarised: (1) a greater force from a given charge was developed in the gun, and brought to bear more directly on the projectile; (2) the weight of the projectile being rateably increased, it absorbed more of the force which was developed behind it; and (3) the greater mass moving throughout its course with a better command over obstacles, vanquished them with greater ease; its broader front displaced more air, but its slower pace created a smaller wave of obstruction.

Instead of the low velocity and heavy shot principle in rifled guns (where the weight was not limited by spherical form) being incompatible with long ranges and great penetration, it would be seen to be more favourable. The greater the range the more marked became the superiority. The 1,200-pounder would deliver blows 45 per cent. heavier at 2,000 yards than the 700-pounder, and it would have upwards of 16 per cent. more penetrative effect. In the comparison between the 7-inch Woolwich gun adopted in 1863-4 and the 9-inch rifled gun proposed by the Author in 1862, it might be observed that, although the small-bore Woolwich gun was able to make rather deeper holes if fired "with the muzzle close to the side of an enemy's ship," yet, at 2,000 yards, where the enemy would more probably be, the 9-inch gun, with 33 per cent. less powder, would have 5½ per cent. greater penetrating power, and nearly 34 per cent. more striking energy. If the range were 3,000 yards, the difference would be still greater, as was shown in the following Table:—

	Woolwich 6½-Ton 115-Pounder: Bore, 7 inches. Adopted, 1863-4.	Britten's 6½-Ton 200-Pounder: Bore, 9 inches. Proposed, 1862.
Initial velocity	1,525 feet per sec.	1,220 feet per sec.
Velocity at 2,000 yards . .	1,078 „ loss 447 feet.	965 „ loss 255 ft.
„ „ 3,000 „ . .	973 „ „ 552 „	910 „ „ 310 „
Initial energy	1,855 foot-tons.	2,063 foot-tons.
Energy at 2,000 yards. . .	927 „ loss 928 feet.	1,291 „ loss 772 ft.
„ „ 3,000 „ . . .	755 „ „ 1,100 „	1,150 „ „ 913 „
Initial energy per inch of shots' circumference. . .	85·3 foot-tons.	73·5 foot-tons.
Energy at 2,000 yards . .	42·6 „ „	45 „ „
„ „ „ 3,000 „	34·7 „ „	41 „ „

Startling as these figures might be to many, they were consistent with the principles of gunnery science which used to be acknow-

ledged and acted upon, before a misconception of the theory of the Minie rifle led to the adoption of small-bored high-pressure heavy-rifled ordnance.

Whether the 35 to 40-ton gun, which the Author suggested, should be constructed partly of wrought iron and steel, and partly of cast iron, as represented in Plate 24, Fig. 5,[1] was of less moment than the vital question, should such weapons have the large calibre he proposed, or the small-bore which had been chosen. The former was a mere question of economy of money, the latter was one of economy of force. With regard to the material, the Author thought it could not be doubted that such a gun as was represented would have sufficient strength for its work. Major Palliser, Mr. Parsons, and Captain Simpson had brought forward facts, showing what compound guns had done when fired as small-bored high-pressure guns with experimental charges, subjecting them to strains three times or four times more severe than any service charges could entail. But in this 15-inch gun no high pressure would be employed. The strength provided was greatly in excess of actual requirements, even without the cast-iron casing; for there was a thickness of about 13 inches of wrought iron or steel to stand a pressure of from 13 to 15 tons per inch. In the 8-inch gun of 7 tons, which had been used for the last two years in testing all kinds of powder, and which had often had to bear 30 tons pressure per inch, there was less than 12 inches of the same metal. Besides this 13 inches of wrought iron and steel in the 15-inch gun, there was a wall of 8 or 9 inches of cast iron as ballast. Altogether there was a thickness of about 22 inches of iron to bear a pressure which was never likely to amount to half as much pressure as the old cast-iron 68-pounders and 32-pounders had to endure from their proof charges.[2]

One objection had been raised to ordnance of this construction, sufficiently plausible to require notice. It was suggested that they might not be safe in the event of premature explosions of shells in the bore. Such accidents in Woolwich guns were not uncommon, but two questions here arose—(1) if it happened in the proposed gun, would it suffer more than a Woolwich gun? (2) need such accidents occur? This 1,200-pounder would be, of course, a battering gun, to be specially used against iron defences. It would mostly be

[1] This drawing was simply intended to convey a general idea of the proposed construction, and was not to be taken as showing precise details. In a working-drawing probably the thickness of the metal towards the muzzle might be made greater. There was plenty of metal to spare at the breech for this.

[2] The pressure of the 10 lb. charges of "Cannon" powder of 1864, with 68 lb. shot in American 8-inch guns, amounted to 18 tons per inch.

fired with shot, and it was doubtful whether it need be fired with shells at all. But if shells were used, they would necessarily be very thick, hold comparatively little bursting charge, and be fired without any fuse, the impact on iron plates being sufficient to cause explosion. The 12-inch service battering shell held about 14 lbs. of powder. The 15-inch 1,200-pounder shell might hold from 18 to 20 lbs. This would not be likely to burst a gun which, at the thinnest part, had a thickness of from 6 to 7 inches of metal, of which 2 or 3 inches would be wrought iron or steel. The bursting charge of a shell exploding in the bore was not like so much powder fired with a shot before it. The gas would be free, as in the case of a blank cartridge, but with this difference, it could expand rearwards if its force was greater than that of the charge behind it, at that stage of its expansion. In the 15-inch gun the pressure of the charge near the muzzle would not exceed 300 lbs. or 400 lbs. per inch. It was impossible, therefore, that any strain could arise likely to endanger such a gun. Major Palliser mentioned having fired several shells containing 14-lb. bursting charges, which were caused to explode, one after another, in a common 68-pounder gun, lined with $2\frac{1}{2}$ inches of wrought iron. Here there was only a thickness of 4 inches of metal near the muzzle, and yet the gun resisted. These shells, which weighed 180 lbs., were projected with 22 lbs. of violent powder. Of the sixty cast-iron rifled guns which were worn out in service during the American war in firing over 31,300 shells, only four failed at the muzzle; and there was nothing to show that in those cases the failure was owing to the premature explosion of the shells. One of these was a 100-pounder of 6·4 inches calibre, the muzzle of which was torn off at the 1,225th round, and the bore had been somewhat worn; yet the thickness of metal (cast iron) at 12 inches from the muzzle of this 100-pounder was only about 3 inches. General Gillmore, who had had more experience than any other commanding officer with cast-iron rifled guns, stated, in his evidence before the American Committee of 1869,[1] "I never regarded the bursting of shells sufficient to burst Parrott guns. I have seen the effect on the bore of shells bursting in the gun, but I never regarded it sufficiently serious to cause the bursting of the gun unless repeated a great many times." The 15-inch cast iron American navy guns used in the war tapered from the trunnions down to a thickness of 3 inches at the muzzle, and these guns were constantly fired with shells holding

[1] *Vide* "Report of Joint Committee on Ordnance" in the Senate of the U.S., February, 1869, p. 50.

over 16-lb. bursting charges. If the muzzles had suffered in such a case it would not have been surprising, considering the bore was 15 inches in diameter. The twelve rifled cast-iron 26-cwt. guns used by the Prussians against Paris fired 3,882 shells weighing about 65 lbs. each. Those guns were only $2\frac{3}{8}$ inches in thickness at 1 foot from the muzzle; and the shells carried as heavy bursting charges as the English 64-pounder shells; but none of these guns suffered. Either the shells were not liable to premature explosion, or, if they were, no harm arose from it. When these premature explosions had occurred in English guns it had arisen either from their being subjected to the crushing "centering" action, concentrated on the parts of the shells where weakened by the stud holes, or else the old fashioned time fuzes had been used. It might be then accounted for by the gas from the extremely heavy charge overlapping the shell, forcing the meal powder back, and so igniting the powder inside. But in other countries only concussion fuzes were used for rifled guns, and there were but few occasions in service when anything else could be preferable. With these fuzes there was no reason for apprehending such accidents,[1] if the inside of the shells were properly coated with lacquer, or the powder was enclosed in serge. If these 1,200-pounder guns were not fired with shells at all, but were able to sink a more heavily-plated ship than other guns which cost three times as much, this alone ought to be sufficient to recommend them.

With reference to the proposal to rifle the old cast-iron guns, without strengthening them or reducing their calibre, it would he thought be conceded, that rifled cannon of moderate size were as necessary for the national defences as monster ordnance. For the land faces of forts; for sea faces where no armoured vessel could approach from want of water; on every salient point where troops could march or small boats swim, guns must be mounted, or strongholds could not be held. Unwieldy weapons would be out of place in such positions; but other guns must be there in great numbers, and with sufficient power to do the work required. As regarded mere range, small rifled guns were equal to the largest. The Author's rifled service guns, even with such charges as he ventured to use of the "poudre brutale," made excellent

[1] It is said to have been a common thing for shells, even with concussion fuzes having movable strikers, to explode in the muzzle of shunt guns. This was due to the "grip at the muzzle," which checked the shot sufficiently for the strikers to run forward and do their duty. The same thing might, doubtless, occur if shot with rigid studs or ribs got jammed.

practice at nearly 6,000 yards. The German army could have bombarded Paris at that distance, but the batteries were brought up to within 2,000 yards. Instead of fewer guns of moderate size being now necessary, it was reasonable to expect that more would be wanted than formerly, because the long range of rifled cannon widened the area of attack, and this involved the necessity of a greater number of batteries for the defence. In the late campaign, which was pre-eminently a war of artillery, France was conquered without a single gun being fired by the victors larger than 60-pounders; but, instead of cannon of large size, great numbers were used.

With few exceptions, British garrison guns consisted at this moment of cast-iron smooth-bores. At Malta there were from 1,000 to 1,500, with only a few rifled guns. It was much the same in the Channel Islands, at Gibraltar, Bermuda, Aden, in India, and in Canada. According to a Parliamentary return[1] presented last Session, it appeared that when the iron-clad ships were supplied, and the new fortifications, built or building, to defend such places as the Thames, Portsmouth, and Plymouth, were armed, only 737 pieces of approved rifled cannon larger than 12-pounders would remain, for all defensive works throughout Great Britain and her foreign dependencies, and all ships save iron-clads. Before, then, British forts could be provided with rifled garrison guns, or the arsenals with siege weapons, like the forts and arsenals of the great continental states, many thousands of such guns would be required. The fighting stock of the nation had hitherto consisted of from 25,000 to 30,000 cannon of all sizes. These still existed, but they were, for the most part, scarcely better than dummies. The undisguised opinion of the arsenal authorities was, that all the old guns should be thrown aside to make way for new wrought-iron guns of the present small-bore type. Before the country was, however, committed to such expenditure as this would involve, it should be clearly shown what benefit was likely to accrue from it. A few wrought-iron guns, of moderate size, had been made, and were in the service. They weighed 64 cwt., and were fired with 8 lbs. of powder and 64-lb. projectiles with studs. Now, by the Author's plan, as it had been carried out in America, the old 32-pounders, of about 58 cwt., were converted at a cost of a few shillings each, also into 64-pounders. They were of the same calibre, and were fired with charges giving as much velocity, range, and penetration as the English wrought-iron 64-pounders, which

[1] "Army (Rifled Guns)," Parl. Ret., No. 177, 24th April, 1871.

were heavier, and cost between £220 and £300 each.[1] Large numbers of these old guns had been so used during a long war, and gave entire satisfaction. Not one was said to have failed.

The only other muzzle-loading rifled guns of this class in the British service, besides 64-pounders (new or converted), was the converted 95-cwt. 68-pounder. The bore of this gun, when lined, was 6·3 inches—the same as the 64-pounders—but it fired projectiles considerably longer, weighing 80 lbs. The same guns were used by the Author fifteen years ago, to fire 90-lb shells, and they proved perfectly trustworthy with sufficient charges of even the violent L.G. powder to render them efficient. It was now proposed to use pebble powder for these converted 68-pounders, as greater velocity was obtained with only half the strain produced by the R.L.G., and still less than with the L.G. The results of these trials enabled the Author to discover what might be done with these old 68-pounder guns if simply rifled as he proposed, and fired with the mild new powder. This would be seen from the following tabular statement:—(p. 317).

The velocity of the 115-lb. shot here assumed was the same as had been obtained with similar charges in proportion ($\frac{1}{10}$th) to the weight of shot in other guns. This being granted, all the other figures were arrived at by calculation. It was plain, therefore, that large sums of money were being laid out in spoiling these guns by reducing their calibre; for at 2,000 yards the 80-lb. shells would strike with less energy by about 35 per cent., and have less penetrating power by nearly 5 per cent., than the 8 inch 115-pounders. By retaining the full bore of 8·12 inches, the Author was enabled to employ projectiles, which, though nearly half as heavy again, did not resist the charge so much as the 80-lb. shot of 6·3 inches in diameter. The 8-inch shells of 115 lbs. weight might be made about two diameters in length, which proportion gave excellent shooting.

As to its being a retrograde measure to go back to cast iron for guns of this nature, that depended upon how far the ordinary notions of the material were correct, and also how far the recent improvements in gunpowder introduced new features into the question. Cast iron, of course, was not so strong as wrought iron; but it was, in the Author's opinion, strong enough for guns of moderate size, and powder of proper quality. There were facts to show that, when properly made, it was not more uncertain than wrought iron; while the latter was more liable to vary in strength from

[1] "Army (Rifled Guns,)" Parl. Ret., No. 177, 24th April, 1871.

CONVERSION OF 68-POUNDER 95-CWT. CAST-IRON GUNS.

Comparison between the adopted plan of Major Palliser, and the plan proposed by Mr. Bashley Britten.

General Details.	Adopted Plan. Bore 6·3 inches. Area of „ 31·1 sq. in.	Mr. Bashley Britten's Plan. Bore 8·12 inches. Area of „ 51·6 sq. in.
Cost of conversion and proof	£250[1] per gun.	£1 per gun.
Charge; pebble powder	12·5 lbs.	11 lbs.
Projectile	80-lb. shell.	115-lb. shot or shell.
Length of cartridge	11·1 inches.	6 inches.
Number of expansions of charge in bore	9·9	18·8.
Carrying power of projectile, *i.e.* weight ÷ area of section.	2·57 lbs.	2·23 lbs.
Maximum pressure[2] on gun per square inch (estimated).	8 tons.	7·75 tons.
Initial velocity	1,300 feet per second.	1,210 feet per second.
Remaining velocity at 2,000 yds.	973 „ (loss 327 feet).	945 „ (loss 265 ft.)
Initial energy	939 foot-tons.	1,169 foot-tons.
Remaining energy at 2,000 yds.	526 „ (loss 413 foot-tons).	713 „ (loss 456 foot-tons.)
Energy at muzzle per inch of shot's circumference	47·4 foot-tons.	46 foot-tons.
Ditto ditto at 2,000 yards	26·6 „	28 „
Differences:		
Greater initial energy	..	24·5 per cent.
„ energy at 2,000 yards.	..	35·5 „
Energy at muzzle per inch of shot's circumference	3 per cent.	
„ „ at 2,000 yards	..	4·7 „

[1] The contract price paid to the Elswick Ordnance Company. The estimate at the Royal Gun Factories was about £230.—(Report of O. S. Com. on "Coiled Wrought-Iron Inner Tubes for Ordnance," presented to the House of Commons, 16th March, 1868.)

[2] The proof charges for the converted gun, viz., 15 lbs. pebble powder and 90-lb. shot, gave a maximum pressure of about 9 tons per square inch, and a velocity of 1,290 feet per second.

unskilful manipulation in large masses. Many experiments had been tried at Woolwich, to ascertain the actual tensile strength of the cast iron used for ordnance. When the question of rifling the old guns was under consideration ten or twelve years ago, the Ordnance Select Committee tested forty-two different samples, and the exact results of the tests were given in the Report of the Committee of 1863. The average tensile strength was ascertained to be 12·71 tons per square inch, and the lowest measurement in the whole series was 11·4 tons per inch. The iron was of the quality supplied by the chief gun

contractors, who, from long experience, had thoroughly learned their art. But other trials of a similar character had been made on a more extensive scale, of iron from various foundries where the art of gun-casting was little understood. At the commencement of the Russian War an urgent demand arose for 13-inch mortars for sea service, and contracts were offered to the general trade. The consequence was that some mortars of inferior iron were obtained. Three of these burst in service, and several others cracked; but whether they failed from the iron not being good, or from the castings being defective, had never been proved. These mortars fired service charges of 20 lbs. of the instantaneous L.G. powder, and shells weighing 200 lbs.; the maximum thickness of the metal in them being $11\frac{3}{8}$ inches. From what was now known of the action of this powder, it was evident that such a charge must produce a strain far greater than that on any of the old long guns, for the powder would all be ignited before the shells moved. When some of these mortars were afterwards tested for endurance at Shoeburyness, two, by experienced makers, fired 2,000 rounds each without bursting. Suspicions being aroused as to the quality of the iron then obtained, an extensive series of "experiments connected with the comparative strength of iron used in the manufacture of certain mortars, in relation to their enduring properties when fired with service charges, &c."[1] was made, under the direction of General Eardley-Wilmot, Superintendent of the Royal Gun Factories. Nothing like "uncertainty" of strength was discovered in any instance throughout all these trials; and not a single specimen broke under a less force than afforded a good margin beyond what would be required to resist the pressure from the charge of pebble powder proposed by the Author for the 68-pounder when rifled. From these experiments, it was clear that the average tensile strength of good cast iron, such as had always been supplied by the great contractors, was from 12 to 13 tons per square inch. It was important also to bear in mind that the element of time had to be taken into account. Thus it occupied less than $\frac{1}{100}$th part of a second for the service charge to expel the 180-lb. shot from a gun 10 feet long in the bore. The maximum force, of nearly 30 tons per square inch, was reached before the shot had moved any appreciable distance. On the shot having moved $\frac{1}{4}$ of an inch, the pressure had come down to 29 tons. To resist this force there was not only the strength of so much iron,

[1] *Vide* "Minutes of Proceedings of the Royal Artillery Institution," vol. i. p. 443. Feb., 1858.

but the inertia of the mass. Before the tensile strength of the iron came into operation, this inertia had, to a certain extent, to be overcome. The power in the material of the gun to resist momentary strain therefore depended on its ability to hold together when stretched within the limits of its elasticity, and to resist stretching; or, in other words, on the quality of rigidity, or incompressibility, which cast iron possessed in a higher degree than wrought iron. It was, no doubt, for this reason that a greater thickness of cast iron could be used with advantage in guns to oppose a sudden passing strain, than was found to be practically available in hydraulic presses, where the pressure was persistent. In no other way could it be explained why cast-iron guns were able to endure the enormous proof-charges of the violent L.G. powder they were tried with. It was evident, from what modern instruments had shown, that the old 32-pounders and 68-pounders were proved with a pressure considerably greater than that which fell on the 35-ton guns with the service charges of the new pebble powder. There were instances on record of ordinary cast-iron guns having endured measured momentary pressures of upwards of 30 tons per square inch.

In considering, therefore, whether the 68-pounder would be safe with the proposed 11-lb. charges of pebble powder, and projectiles of about 115 lbs., the question narrowed itself to this:—as the metal of the gun was known to be strong enough to endure, for some seconds at least, an extreme force of from 12 to 13 tons per square inch before it broke, would it be likely to yield to a force of about $7\frac{3}{4}$ tons per inch acting for only, perhaps, the four or five-thousandth part of a second?

The same remark applied to the proposed employment of cast iron for the exterior of large ordnance. In the absence of evidence to the contrary, it might be assumed that the old guns would be strong enough if converted as the Author proposed. Would it not, then, be wise to determine this practically before any further sums of money were spent in converting them, as was now being done, into weapons of inferior power? Last year the Author asked to be allowed to prove that, under the specified conditions, the service rifled guns would be subjected to less strain than when fired as smooth-bores with the heavier service charges of the old violent powder. He contended that if they were safe with these, they would be safe with less strain; and that the strains in both cases could be measured and compared. But although he offered to bear the cost of the experiments, the requisite permission was not granted.

Note by the Author.

Since the Paper was read the authorities at Woolwich had made some experiments which set at rest the questions which the Author had raised. They had compared the relative efficiency of large and small calibres, by boring out the 10-inch experimental gun to a calibre of 11 inches, and by taking accurate observations of pressures and velocities. The results entirely confirmed what had been advanced in the Paper.[1] Through the courtesy of General Adye, he had obtained the following:—(p. 321).

In these experiments four gauges were used; one, designated A, was placed at the end of the bore in the axis; another, B, at 11 inches from the end, or about the middle of the space occupied by the powder; another, C, at 25 inches, near the extreme end of the cartridge; and the fourth, No. 1, at 38·3 inches, where it was opposite the front end of the shot. The effects of 70 lb. and of 85 lb. charges of the same powder, with 400-lb. shot, were compared.

The enlargement of the calibre to the extent of 1 inch made the following difference in the conditions. The charge of 85 lbs. took up no more length of the 11-inch bore than 70 lbs. did in the 10-inch; so that there was just as much relative expansion of the charges. The shot, however, in one case presented a larger area to the pressure, and consequently offered less resistance. The actual conditions of the charges in each bore were—

Shot, 400 lb. each.	Per inch of area.	
10-inch bore. Area, 78·5 in.		
Charge, 70 lbs.	= ·89 lbs. powder	} to propel 5·1 lbs. shot.
Charge, 85 „	= 1·08 „ „	
11-inch bore. Area, 95 in.		
Charge, 70 lbs.	= ·73 lbs. powder	} to propel 4·2 lbs. shot.
Charge, 85 „	= ·89 „ „	

[1] Previous to the 35-ton gun being tried, the Author published a work last year on "Heavy Rifled Ordnance," in which he pointed out that this weapon, with the calibre of 11·5 inches, must prove a failure. This work was sent to the War Office and to the Royal Gun Factories for consideration. Some months after this the 35-ton gun was bored out to 12 inches, and was found to be greatly improved, though still unable to burn the charge it was designed for, viz., 120 lbs. of pebble powder.

TABLE giving the RESULTS of EXPERIMENTS made in June, 1872, with the 10-INCH GUN, No. 375, and the same Gun bored out up to 11 inches. The Projectile in both cases was 400 lbs. in weight; the only variables being the calibre and the charge of powder.

	Round.	Observed Velocity.	Pressure by Crusher Gauges. Tons per Square Inch.				Mean Pressure on Gauge A in Axis.
			Gauge A. Axis.	Gauge B. 11 Ins.	Gauge C. 25 Ins.	Gauge 1. 38·3 Ins.	
		ft. per sec.					
PEBBLE POWDER, *Lot* 863.							
10-inch, charge 70 lbs.	1	1,334	16·3	16·5	15·1	13·5	17·7
	2	1,356	18·8	17·1	16·4	16·4	
	3	1,364	18·2	18·1	18·6	16·8	
11 „ „ 70 „	1	1,349	13·4	13·3	13·2	9·9	13·3
	2	1,350	13·5	12·9	13·5	10·4	
	3	1,338	13·5	13·0	11·8	10·6	
	4	1,336	12·9	12·8	11·1	10·2	
10 „ „ 85 „	1	1,473	46·0	30·0	25·1	35·5	38·6
	2	1,479	28·8	22·2	26·0	27·0	
	3	1,463	41·0	26·5	23·0	34·7	
11 „ „ 85 „	1	1,484	19·3	18·3	19·4	14·0	19·3
	2	1,465	18·1	17·0	18·0	12·6	
	3	1,466	20·7	16·0	15·6	14·0	
PEBBLE POWDER, *Lot* 1,404.							
10-inch, charge 85 lbs.	1	1,396	37·3	23·9	24·1	23·5	39·8
	2	1,408	45·8	21·3	28·0	28·9	
	3	1,363	36·3	19·7	24·7	23·3	
11 „ „ 85 „	1	1,441	17·2	16·3	16·8	12·5	16·4
	2	1,433	16·4	16·1	13·3	13·1	
	3	1,427	15·6	14·9	15·6	12·3	
	4	1,446	16·5	15·3	14·9	12·5	
10 „ „ 70 „	1	1,352	21.3	18·0	19·1	17·6	21·2
	2	1,344	22·9	20·9	19·7	16·7	
	3	1,339	22·0	19·2	18·5	16·5	
	4	1,321	18·5	18·1	18·1	16·6	

The larger calibre consequently enabled the same gun to fire upwards of 21 lbs. more powder without being subjected to so much strain. The mean pressures and velocities were as follows:—

EXPERIMENTS made in June, 1872, to ascertain the effect of enlarging the calibre of the 18-ton 400-pounder Woolwich Rifled Gun from 10 to 11 inches; the only variables being the calibre and the charge of powder.

7 ROUNDS EACH.	Mean Maximum Pressure on Gauge A in axis of Gun.	Mean Velocity.	Energy (Initial).	Punching Power (Initial). Energy per inch of Shot's Circumf.
	Tons per square inch.	Feet per sec.	Foot-tons.	Foot-tons.
11-inch rifled gun, charge 85 lbs. powder, shot 400 lbs.	17·8	1,452	5,855	172·2
10-inch rifled gun, charge 70 lbs. powder, shot 400 lbs.	19·4	1,344	5,016	161·8

Thus in the 11-inch gun with less pressure there was an increased energy of 16·7 per cent.

When 85-lb. charges were used in the 10-inch bore, the mean velocity in 6 rounds was 1,430 feet, and the mean pressure on gauge A was 39·2 tons per square inch, while in the 11-inch bore it was only 17·8 tons with the same charge. In firing these 6 rounds of 85-lb. charges in the 10-inch bore, no less than three cases of what had been termed "irregular pressures" occurred. The mean of 39·2 tons per inch included one instance of 46 tons, another of 45·8, and another of 41 tons; these all fell on one part of the gun—not on the side gauges, but on the gauge at the end of the bore in the axis. These abnormal strains were stated to be due to irregularities in the combustion of the powder. But if this were the cause, it remained to be explained why the excessive pressure should be found at the bottom of the bore, and only in certain rifled guns when the hard studs had excessive work to perform. As the powder ignited, the gas must act according to an invariable law, and the pressure over the whole surface would be equal, and gradually diminish as the shot advanced and the gas expanded. That such was the rule when all went well was shown by the gauges on the sides B, C, and 1. The irregularities did not appear when the gun was not overloaded, and the hard studs thereby wedged too tight. The liability of such shot to override the rifling and jam themselves, was clearly greater when either a higher velocity was being imparted, or when the shot themselves were longer and heavier on the rifling; the studs then had more to do in acting through a shorter radius. But if they rode up over the rifling from any cause, and the studs (or iron ribs, as some proposed) had to be ground away to release the shot, the gas,

having acquired motion, and moving as a column or stream in one direction, its elastic force must culminate, when it met with a check, till the obstacle was overcome. But it would culminate first at each end of the moving column, and so fall heavily on gauge A at the end of the bore, while it would not affect the gauge B at the side until the direction of the force was deflected laterally, and the *vis viva* of the gas diffused itself as pressure. It was only necessary to assume the possibility of the hard metal stud shot and the Woolwich centering, or wedging, rifling being the cause of irregular resistances from the projectiles in the passage through the gun, and these mysterious local pressures might then be referred to the physical law that action and reaction were equal and contrary.

This 18-ton (original 10-inch) gun was now precisely the same as the service 25-ton 11-inch 535-pounder, in all respects except in external dimensions and weight. When fired with 400-lb. shot and the service charge for 11-inch guns (85 lbs.), it afforded an exemplification of the principle of "high velocity and large charges." When, however, it was fired with the same or even less charges, and advantage was taken of the large calibre to fire heavier projectiles, it became an exemplar of the low velocity principle which the Author advocated. The following figures had reference to these two principles:—

EFFECTS of LARGE CHARGES and HIGH VELOCITIES compared with smaller relative Charges producing lower Velocities in combination with greater weight of Projectile.

——	Charge.	Shot.	Carrying Power. —— Weight of Shots to Area of Section.	Mean Maximum Pressure.	Initial Velocity.	Initial Energy.	Initial Punching Power.
	lbs.	lbs.	lbs. per sq. inch.	foot-tons.	feet per sec.	foot-tons.	foot-tons per inch of circumference.
10-inch bore . . .	70	300	3·8	15·6	1,521	4,819	154
Ditto . . .	..	400	4·2	19·7	1,344	5,016	161·8
Ditto . . .	..	600	7·5	21·1	1,128	5,300	171
Ditto . . .	85	400	4·2	39·2	1,430	5,679	180
11-inch bore . . .	85	400	5·1	17·8	1,452	5,855	172
Ditto . . .	..	535	5·7	?	1,315	6,415	187

The figures were taken from the official reports of experiments made at Woolwich with the experimental 10–11-inch gun.

From this it was obvious that the axiom, as to the power of projectiles being more dependent on velocity than weight, was fallacious; yet this was the central idea on which the Woolwich system of rifled artillery was founded. The 10-inch gun with its service charge of 70 lbs. produced with 300-lb. shot a velocity of 1,521 feet, and a punching power at the muzzle of 154 foot-tons; the same charge with 600-lb. shot gave a velocity of only 1,128 feet, but its punching power was then 171 foot-tons at the muzzle. In 2,000 yards the 300-lb. shot would lose about 420 feet velocity (nearly 40 feet less than the service 115-pounders),[1] so that it would have only about 1,100 feet remaining; whereas the 600-pounder, starting more slowly, and having greater carrying power in its mass, would lose so much less that at this range it would have comparatively little less velocity than the 300-lb. shot, but this would be accompanied with twice the weight. It must be noted, however, that shot of 600-lb. were inconveniently long for a 10-inch gun; therefore the service shot weighed only 400 lbs. To get with these something like the power obtained with the 600-lb. experimental shot, higher velocities from larger charges were tried. The 10-inch gun was fired with 85 lbs. of powder, and 400-lb. shot. The velocity then obtained was 1,430 feet, equal to a punching power at the muzzle of about 180 foot-tons. The 600-lb. shot, with 70 lbs., gave 171 foot-tons, but produced it in a form which was more useful, because at 2,000 yards it would retain about two-thirds more force. To get greater power by using larger charges of powder, subjected the gun to twice the pressure. The larger calibre was then tried. The 10-inch bore being enlarged to 11 inches, enabled the gun to do much more work with greater safety. The heavy projectile, which before was too long, now became capable of being used; and the charge (85 lbs.), which before was too violent, now became tractable. Instead of maximum pressures of 45 and 46 tons per inch, the highest strain on the 11-inch gun, firing the same charge (85 lbs.), and shot of the same weight (400 lbs.), was less than half (20·7 lbs.).

This 18-ton gun had now become an 11-inch gun, like the others in the service of that calibre, and if the service projectiles of 535 lbs. were used, they would not be nearly so severe on the powder as the 600-lb. 10-inch shot were. The former offered 7·5 lbs. per inch of area, and the latter only 5·7 lbs.; consequently the gun could now produce 6,415 foot-tons striking energy, instead of only 5,016 tons, as a 10-inch gun; and it had a punching power of

[1] *Vide* "A Text Book of Rifled Ordnance," p. 194.

187 foot-tons, instead of only 162 foot-tons. In doing this it had little more pressure to bear, if proper shot were used, and it need not be stronger. Here another element came in. It could not so be used, because it was too light. Eleven-inch service guns of 25 tons were sufficiently lively with service charges; but this gun weighed less than 18 tons. Supposing, then, to enable this gun to be so used, it was ballasted with a casing of cast iron. No question need be asked whether this material was strong enough. The exterior casing would answer much the same purpose as the Author proposed it for in his 15-inch gun.

April 30, 1872.

T. HAWKSLEY, President,
in the Chair.

The discussion upon the Paper No. 1,336, "On the Construction of Heavy Artillery," &c., by Mr. Bashley Britten, was continued throughout the meeting.

May 7, 1872.

T. HAWKSLEY, President,
in the Chair.

His Royal Highness Prince Arthur William Patrick, K.G., K.T., K.P., was unanimously elected, by acclamation, an Honorary Member.

The following Candidates were balloted for and duly elected :— John William Gray, David Rowan, Walter Henry Scott, and Lionel Bury Wells, as Members; Edgar William Beckingsale, Edward Pearce Brown, Stud. Inst. C.E., Edmund Small Cathels, Archibald Crellin Cregeen, Charles Edward Gael, B.A., James Henry Greaves, Stud. Inst. C.E., Charles Godfrey Gumpel, John Prentis Hawley, Thomas Howard Head, Lieut.-Colonel Percival Robert Innes, John Peake Knight, Rai Kunhya Lall, Simon McBean, Frederick Herbert Mollett, Stud. Inst. C.E., William Morris, Henry Thomas Munday, Stud. Inst. C.E., Thomas Nuttall, James Smith O'Kell, David Reid, Thomas Reynolds, Stud. Inst. C.E, Charles Edward Robinson, Stud. Inst. C.E., Francis Frederick Smith, and Frank Napier Thorowgood, Stud. Inst. C.E., as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VIII., of the Bye-Laws, had transferred WILLIAM DYCE CAY, HENRY HOOPER, FRANCIS LANGFORD O'CALLAGHAN, and JOHN ROBINSON from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:— GILBERT BERESFORD, WILLIAM PATRICK BRODIE, STEPHEN FINNEY, JOSEPH EDWARD FISHER, CHARLES WILLIAM HODSON, LLOYD MACDONALD HUGHES, MARMADUKE JOHN MONCKTON, RALPH SADLER, ERNEST IFILL SHADBOLT, JAMES TAIT, CHARLES JAMES KNIGHT WATSON, HORACE WILMER, WILLIAM JOHN WILSON, and TREVREDYN RASHLEIGH WYNNE.

The discussion upon the Paper No 1,336, "On the Construction of Heavy Artillery," &c., by Mr. Bashley Britten, was continued throughout the meeting.

May 14, 1872.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—John Percy, M.D., F.R.S., as an Honorary Member; George Henry Bayly, as a Member; John Henry Holland, Charles George Kleberg, George Brooke Muriel, Henry Rigg, Edward de Romaña, Arthur Shanks, John Wade, Charles Robert Western, Stud. Inst. C.E., and Thomas Plantagenet Bigg Wither, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—John Dickson, Jun., Joseph Hayward, Valdemar Lassoto, and Joseph Tysoe.

No. 1,342.—"Explosive Agents applied to Industrial purposes." By Frederick Augustus Abel,[1] F.R.S., Treas. C.S.

The almost complete monopoly which gunpowder has, until quite recently, continued to enjoy, as the explosive agent applied to industrial purposes, is not ascribable to any lack of attempts to supplant it in its various uses. It is due partly to the low price at which mining or blasting powder is manufactured, but principally to the almost universal familiarity with its employment and general effects, and to the confidence in the unchangeable nature of its behaviour and properties, which are the natural results of its great antiquity and of the remarkable fact, that the most strenuous and persevering efforts to attain, by other explosive agents, the results which it furnishes in some of its most important applications (especially connected with war purposes) have hitherto proved unsuccessful.

As gunpowder is simply a mechanical mixture, in variable proportions, of certain solid substances which are capable of reacting upon each other chemically, the result being the partial

[1] It was announced that the Discussion upon this Paper would be taken at the first meeting of the next session.

transformation of the solid mixture into gaseous matter and the development of great heat, it follows that the explosive force which such a mixture is capable of exerting is liable to considerable variation. Thus, it may be regulated by the following circumstances, either separately or collectively: the proportions in which the ingredients are employed, the degree of intimacy or completeness with which they are mixed, and the mechanical condition or form which the mixture has taken. This liability to a variation in explosive force or strength, though it constitutes an important advantage with respect to some of the uses of gunpowder, has an undoubtedly detrimental effect upon its value in many of its applications to industrial purposes and upon its position with reference to other explosive agents, inasmuch as it has caused competition to effect such reductions in the cost (and consequent perfection of manufacture) of mining or blasting powder, as to diminish greatly the results attainable with the ordinary descriptions of powder sold under those designations. Gunpowder has certain defects which are inherent in the material: thus, it is liable to deterioration by keeping, in consequence of the absorption of moisture; and this is especially the case with powder made for mining purposes, because this powder is more porous, and less carefully finished, than war powder, and also because it is generally made with only imperfectly refined, or even with unrefined, saltpetre. The quantity of smoke produced by the explosion of powder is a source of inconvenience and loss of time in underground blasting operations; and the circumstance, that if gunpowder becomes ignited from any cause it must explode violently, is a constant source of casualties in mining districts. The proposal to render gunpowder safe in store, by diluting it, or interposing inert materials between its grains, which was revived by Mr. Gale in 1865, has not found favour, for reasons which cannot now be discussed; but it may be hoped that careful legislation will shortly tend to reduce the number of accidents, which arise in this country chiefly from the almost inconceivable recklessness displayed in the storage and handling of gunpowder by its vendors in mining localities. Even then, however, the casualties due to neglect of ordinary precautions, or to the extreme carelessness of those using gunpowder in mines and quarries, are hardly likely to be reduced in number.

The successful employment of tunnelling machines within the last few years has demonstrated, more forcibly than could otherwise have been done, the great advantage, in saving of time, which must accrue from the employment of a more powerful blast-

ing material than common gunpowder. But even in many ordinary blasting operations, there is no difficulty in showing that an important saving of time and labour may be effected in many kinds of work by employing a more powerful explosive agent than blasting powder; the possibility of using blast holes of reduced dimensions, and of increasing their distance from each other without detriment to the magnitude of the results, being advantages of the most obvious description. It appears to have been repeatedly demonstrated by practical trials that, in the removal of hard rock, in tunnelling, and in other operations of this class, decided advantages are gained in point of rapidity of work, by the employment of gunpowder of higher quality than ordinary mining powder; but those advantages will not bear comparison with the results attainable by the employment of certain explosive agents of a decidedly more violent character. There are, however, some directions in which ordinary blasting powder does not appear to be replaceable with advantage, if at all, by the explosive agents which are formidable rivals to it in other directions.

Before discussing the substances which have been proposed and employed as substitutes for gunpowder in industrial operations, it may be advisable to refer in very few words to the action of that substance, and others of a similar nature. The explosive properties of a mixture of saltpetre, charcoal, and sulphur, such as gunpowder, are primarily due to the powerful oxidising power of the nitric acid compound known as saltpetre (or nitrate of potash), or, in other words, to the rapid and energetic manner in which oxidisable substances (such as carbon) are burned by the oxygen, of which saltpetre contains a large supply, held in feeble combination, and therefore ready at any time to enter into more stable combinations with other substances, when conditions favourable to chemical change are fulfilled. Nitric acid itself, in the free state, possesses this same property of violently attacking oxidisable bodies, and combinations of that acid with other metals (*e.g.*, sodium and barium) are obviously also endowed with similar oxidising power. The violence of explosions developed through the agency of these substances depends upon the energy and rapidity with which they attack oxidisable substances, upon the volume of gas or vapour rapidly or suddenly liberated by the chemical change, and upon the heat developed by that change. It also depends, in some measure, and to a variable extent, upon the conditions under which the chemical reaction between the substances constituting the explosive mixture is developed.

The oxidising properties possessed by nitric acid and the nitrates are shared by numerous other bodies known to chemists, among others by a class of compounds of analogous nature to the nitrates, known as the chlorates, in which the large supply of oxygen is held in comparatively very feeble combination by chlorine, as in the nitrates it is held combined by nitrogen. The chlorates are much more readily decomposed, and are therefore more powerful oxidising agents, than the nitrates, and hence, when mixed with oxidisable substances, such as carbon and sulphur, they furnish more violently explosive mixtures.

Ever since the chlorate of potash has been produced upon a manufacturing scale, attempts have been made from time to time to utilise its comparatively violent oxidising power in the production of explosive mixtures more powerful than gunpowder, and applicable to its various uses.

Preparations consisting of chlorate of potash mixed with certain sulphides, with the prussiates of potash, with sugar or starch, these substances being either employed alone or in admixture with sulphur and other substances, have been brought forward at various times, and under a variety of names, as gunpowder-substitutes, the earliest of them being known as German gunpowder, and white gunpowder; but the property which they all possessed, of being exploded when submitted to comparatively moderate friction or percussion, was alone sufficient to prevent their being accepted as practically useful explosive agents, even if decided advantages could have been established for them by a proper comparison of their cost and efficiency with those of gunpowder. Ingenious attempts have been made to reduce the dangerous nature of chlorate of potash-mixtures by impregnating or covering them with inert materials designed to serve as protective agents, by absorbing or deadening the violence of blows, friction, or concussion to which they might be subject; but, while such contrivances were only partially successful in guarding against liability to accident, they so considerably reduced the rapidity and violence of explosion of the materials to which they were applied as to preclude these from competing successfully with powder from an economical point of view.

A few comparatively safe preparations containing chlorate of potash have, however, been devised, some of which have furnished results in competition with powder, as mining and quarrying agents, so far favourable as to render it probable that they would have met with somewhat extensive application, but for the practical development of another class of explosive agents,

which have within the last few years become formidable rivals of gunpowder. These chlorate-preparations are of several descriptions; one kind consists of mixtures of the salt with organic substances containing, in addition to carbon, a considerable proportion of hydrogen, such as powdered nut-galls, tannin, and resins. The preparation of powdered nut-galls and chlorate, known as Horsley's powder, which may be considered the type of these mixtures, has been found in practice to possess decided superiority over gunpowder in regard to violence of action, and to be much safer than any chlorate-preparation previously used. Another preparation, in which chlorate of potash was applied with comparative safety to blasting and other purposes, was first devised by Messrs. Hochstädter in 1860, and subsequently reproduced with slight modification by M. Reichen. Strips of bibulous paper were soaked in a pasty mass consisting essentially of a mixture of chlorate of potash, saltpetre, charcoal (and small quantities of other readily oxidisable substances), together with a little gum or other binding material dissolved in water. The paper became coated with the explosive mixture, and, at the same time, impregnated with the oxidising salts, of which it absorbed part of the solution; the strips were rolled up tightly while wet, and when dry furnished hard and compact cylindrical masses, which were violently explosive when confined, but resisted detonation to a very high degree when submitted to percussion or friction.

Some other comparatively safe applications have been made of chlorate of potash to the preparation of explosive agents for mining purposes, by only partly replacing saltpetre with it in mixtures of similar composition to ordinary gunpowder, or containing sulphides besides free sulphur. A substance called Tutonite, for which special advantages as a blasting agent have recently been claimed, appears to belong to this class of preparations. It possesses the peculiarity of being made up in the form of somewhat hard pellets or disks, instead of being in the granulated or pulverulent form.

A few explosive agents have been applied as substitutes for gunpowder (and proposed in the first instance purely for industrial purposes) which present this peculiarity—that their claim to consideration has been based, not, or only in a minor degree, upon superiority in point of power, but upon special advantages in point of economy, safety in manufacture and use, and peculiar fitness for employment as blasting agents. One of these was specially a "safety-powder," devised by Messrs. Kellow, and manufactured near Plymouth a few years ago. It consisted of spent tan and saw-

dust, which were saturated with saltpetre or nitrate of soda and a little chlorate of potash, the product being afterwards very crudely mixed with sulphur.[1] This preparation simply deflagrated with some difficulty when set fire to in open air; but when used with tamping, in the ordinary way, it appears to have competed very fairly with blasting powder. Another blasting agent of this class was invented in 1862 by a Belgian officer, Captain Wynants, and consisted of a mixture of charcoal and nitrate of baryta, either alone or with a proportion of saltpetre. The objects aimed at in producing this "poudre barytique," or "saxifragine," were, in addition to economy, the production of a powder which should act with gradually accumulating force, and which should only be applicable as a blasting powder, so that supplies placed in the hands of miners could not be diverted to other purposes. The first-named object was certainly attained, the baryta-powder being comparatively very slow-burning; and its special characters are such that its application could not but remain limited to ordinary mining and quarrying uses, although its inventor did after a time propose that it should be applied, by admixture with ordinary cannon-powder, to moderate and regulate the pressure exerted by heavy charges in guns of large calibre; a result which has been attained with great success, and in a more philosophical and practically efficient manner, by simple modifications of the physical and mechanical condition of ordinary gunpowder.

It may not be out of place to refer briefly to the fallacious belief, which appears to be frequently entertained by inventors of explosive agents for blasting purposes, namely, that a material which is capable of competing successfully with powder, or of maintaining a superiority over it, in mining operations, must also possess corresponding points of superiority over gunpowder applied to artillery, small arms, and other war purposes. Less smoke, less fouling, and greater penetrative power, are points of superiority often claimed for preparations, which, like the mixture of chlorate of potash with nut-galls and similar products, are to some extent successful rivals of gunpowder in its industrial applications, but which cannot be made to combine the comparatively gradual action of powder with the uniformity essential for artillery or small arms. A high explosive power is, furthermore, not the only essential qualification of a powder or other preparation to be employed in shells or in military engineering

[1] A blasting powder, now being manufactured under the name of "Pyrolithe," bears a close resemblance to Kellow's powder in its composition.

operations. Freedom from liability to explosion by the violent concussion to which a shell is exposed in the bore of a gun; safety in transport and during manipulations by which the material may be subject to friction or concussion, are among the most indispensable conditions to the application of the explosive agent to service purposes, and are not to be set aside by the impracticable alternative, almost invariably suggested as an important advantage by the proposer of a new explosive mixture, namely, that of keeping the ingredients, which in themselves are harmless, separate until just before the material is required for use, thereby postponing any risk of accident, but accumulating it within a period when it can least readily be guarded against, and resorting to wasteful expenditure of sources of force, in the shape of crude mixtures, as a means of partially counteracting those very properties which render the material specially valuable when applied to its legitimate uses.

One other class of explosive mixtures, of which either saltpetre or chlorate of potash is an essential ingredient, must be briefly referred to, because, though their application to blasting purposes has only been attempted to a limited extent, they have lately attracted some attention, as being agents of considerable power.

Among the numerous products obtained by the action of nitric acid upon materials of organic (animal or vegetable) origin, one of the earliest discovered possessing explosive properties is the product known as picric acid, or carbazotic acid, which is furnished in that way by indigo and various other organic substances (Addenda, § 1). Though discovered in 1788, it was only prepared in small quantity until within the last twenty years, but it is now readily manufactured from the coal-tar product known as carbolic acid, and has recently become an important article of commerce as a cheap and brilliant yellow dye. Its salts are all more or less explosive, the picrate of potash, one of those most easily prepared, being especially so. This, when mixed with saltpetre or chlorate of potash, particularly with the latter, furnishes products which, in violence of action, more nearly resemble gun-cotton and nitroglycerine-preparations than does any other readily procurable explosive agent. Both mixtures are susceptible of detonation by friction, and especially that containing chlorate of potash, which is indeed inapplicable to practical purposes on account of its dangerous nature. M. Designolle devoted considerable attention, a few years ago, to the production of safer mixtures of picrate of potash for artillery and small arms, and for blasting purposes; one of these, consisting of picrate of potash, saltpetre, chlorate of potash, and

charcoal, was experimented with at Le Bouchet on a considerable scale about four years ago with some favourable results; but the experiments were abandoned in consequence of a disastrous explosion which occurred at a factory in Paris where considerable quantities of picrate of potash were stored. Much more satisfactory results have been recently obtained in this country in Government experiments with a preparation containing another salt of picric acid, the picrate of ammonia, which, by incorporation with saltpetre, furnishes one of the safest explosive mixtures of a violent character yet produced; and though it cannot compete with nitroglycerine-preparations or gun-cotton in regard to its explosive force, yet it is decidedly stronger than gunpowder. It is, moreover, of perfectly stable character, is readily manufactured in the same way as ordinary gunpowder, and its cost is moderate. It has been hitherto experimented with almost exclusively in reference to the desirability of providing the service with a shell-powder more powerful than gunpowder, and capable of sustaining the concussion of the discharges in heavy guns without the slightest risk of premature explosion. These requirements appear to be satisfactorily fulfilled by it, and a considerable quantity has recently been manufactured for the purpose of comparing it with gunpowder and other explosives as an agent for submarine operations.

Various other products of the action of nitric acid upon substances of organic origin are endowed with explosive properties, but only two of these have, up to the present time, received successful application as substitutes for gunpowder; and it is by preparations of these two substances, nitroglycerine and gun-cotton, that gunpowder has been replaced with considerable advantage in some of its important industrial applications.

Gun-cotton and nitroglycerine (Addenda, §§ 2 and 3) were discovered within two years of each other; but, while attempts were almost immediately made to apply gun-cotton to industrial purposes, its nature and the conditions essential to its successful development as a useful and reliable explosive agent being at the time very imperfectly understood, nitroglycerine was destined to remain a chemical curiosity for about sixteen years. It need scarcely be said that gun-cotton did not long maintain the advanced position into which it was forced at an early stage of its history. Disastrous accidents in England and in France, which occurred within three years of its discovery, completely destroyed the unbounded confidence too hastily placed in the mastery supposed to have been attained over its manufacture and properties; they led to its entire abandonment in England and in France for about sixteen years, and it was only

in Germany that faith in its ultimate success was not altogether lost, thanks to the untiring perseverance of an Austrian artillery officer. Yet the early applications of gun-cotton, especially in England, were not without importance; the well-known gunpowder-makers, Messrs. Hall, of Faversham, entered energetically upon its manufacture within a year of its discovery; its important superiority over gunpowder in many mining and blasting operations was soon made manifest, and the demand for mining charges (consisting of gun-cotton wool tightly rammed into cardboard cases) was steadily increasing, when Messrs. Hall's works were destroyed by the explosion of 1847. Numerous specimens of gun-cotton, made soon after the announcement of Schönbein's discovery, have remained quite unchanged to this day; these and portions of the products of manufacture at Faversham, some of which, after having been buried since the time of the explosion, were recovered nine years ago, and are now in a perfect condition, demonstrate that even in those days stable gun-cotton was sometimes produced, and indicate that the accidents at Faversham and in France, which appear beyond doubt to have arisen from spontaneous ignition during manufacture or storage, were due rather to uncertainty in regard to the quality of the product obtained than to an inherent instability of the properly prepared material (Addenda, §§ 8–19).

It was not until 1864 that gun-cotton again began to receive attention at the hands of practical men in this country, as an explosive agent susceptible of application to industrial purposes. Its manufacture had in the meantime been carefully studied and decidedly improved by Baron von Lenk (Addenda, § 5), who had also devised a system of applying gun-cotton which appeared to afford prospects of rendering it much more readily susceptible of adaptation to different purposes than the original gun-cotton wool of Schönbein. The cotton was spun into loose threads or yarn before conversion, and the finished gun-cotton yarn was either wound, or plaited, or twisted into rope, according to the purpose for which it was to be used, whether in guns, small arms, shells, or mines. Von Lenk's mining charges consisted of pieces of suitable length of a compact gun-cotton-twist or rope, kept hollow in the centre, for the double purpose of receiving the fuze and of causing the charge, when inflamed, to ignite throughout more readily than it would if quite solid, unless strongly confined. Gun-cotton in this form was made the subject of an extensive series of experiments by Baron von Ebner, of the Imperial Austrian Engineers, with the view of testing its applicability to the various military and civil mining

and engineering operations to which gunpowder is applied. For blasting in hard rock, the operation being conducted just as with gunpowder, the force of gun-cotton was found to be so superior that, spite of its comparatively high price when made according to von Lenk's system, a decided saving in cost was effected. In comparatively soft rock the results, though less marked, were still advantageous, provided the rock was free from fissures; if these existed, in any kind of rock, the efficiency of the gun-cotton was more or less seriously interfered with, as its full explosive force was not developed unless the material was closely confined at the moment of explosion. For submarine operations, gun-cotton in the form of rope offered decided advantages over powder, provided it was confined in strong cases, and gun-cotton was consequently adopted as the explosive agent in the submarine mines which were applied to defensive purposes by the Austrians in their last war. The absolute necessity for strong confinement of the material was, however, a serious obstacle to its ready and effective employment in open-air operations, such as the destruction of stockades, or the hasty demolition of bridges, buildings, or works; for although Baron von Ebner described some successful operations in his report, the gun-cotton having been confined in cases constructed of stout wood and sheet metal, the fact that even strong receptacles of this kind could not be relied upon, to afford the initial resistance essential to the proper explosion of the gun-cotton, was demonstrated by repeated failures in the course of the demolition of works at Corfu by the Royal Engineers in 1863, when attempts were made to apply large charges of gun-cotton rope, furnished for the purpose in specially constructed cases by the Austrian Government.

The explosion, in 1862, of a magazine near Vienna, where 28 cwt. of gun-cotton were stored with a quantity of gunpowder, and one of much greater magnitude in 1865, of neither of which any satisfactory explanation was afforded, led to the abandonment of gun-cotton in Austria (Addenda, §§ 7–19); but, meanwhile, experience in the manufacture of the material according to von Lenk's system, and in its application to industrial and other purposes, was being acquired in this country.

In October, 1864, at which time gun-cotton manufactured by Messrs. Prentice, of Stowmarket, was already being used to an experimental extent in some mining districts in England, the special committee appointed by Government, under the presidency of Sir Edward Sabine, to investigate the merits of gun-cotton made and

used according to the Austrian system, instituted a series of comparative experiments with gunpowder and gun-cotton in the lead mines and quarries of Mr. W. B. Beaumont, M.P., near Allenheads.[1] In attempting to form some estimate of the relative power and efficiency of the two explosives, the committee became strongly impressed with the great difficulty of instituting really comparative blasting and quarrying operations. In rock which appears uniform and quite sound, the blasting often brings to light veins, shakes or fissures which render a comparison of work done in two contiguous portions impossible. Even in very homogeneous hard rock, differences in structure occur which modify the resistance opposed to the explosive agent, while it is almost impossible to have two blast-holes, for comparative experiments, so placed in actual practice that their position with reference to the exposed surfaces or faces of the rock, or, in other words, the direction of least resistance, should be more than approximately alike. The results obtained at Allenheads were in most instances favourable to gun-cotton, bulk for bulk, but they varied considerably among themselves for the reasons given, and the committee could not attempt to express any decided opinion as to what might be considered the relative equivalents of gunpowder and gun-cotton used on the Austrian plan. One of the committee, Mr. Sopwith, M. Inst. C.E., whose judgment in these matters is entitled to great consideration, believed that trustworthy data regarding the relative power of different explosive agents would be best obtained, by performing blasting experiments in artificially prepared homogeneous masses as closely alike as could possibly be insured; he suggested blocks of carefully prepared concrete as a suitable material. A few experiments on a comparatively small scale, which the Author executed with concrete blocks, indicated that more trustworthy results might thus be obtained than by comparing the results of ordinary blasting operations; but precise experiments in this direction have as yet been of a limited character.

One decided advantage which gun-cotton was found to possess as a blasting agent, in the experiments of the committee, and which was confirmed by practical experience in underground work, was the absence of smoke; the miners were enabled to return to their work in a much shorter time after a blast with gun-cotton than when powder was used; but this was not the case if the rock operated upon was unsound, or if the resistance opposed to the

[1] Reports relative to the application of gun-cotton to mining and quarrying operations, printed for the House of Commons, April, 1869.

gun-cotton was insufficient to develop its full explosive force; the incomplete explosion of gun-cotton being attended by the development of vapours of an irritating character, which could not be inspired without much inconvenience. An important objection to the Austrian mining charges of gun-cotton-rope was the comparatively loose condition, or the want of rigidity, of the material, which caused it to be easily altered in shape (or upset) if any force were used in pushing a somewhat tightly-fitting charge down a hole; if an attempt was then made to drive home the charge it became tightly jammed, and several accidents occurred in consequence of the explosion of charges of gun-cotton-rope by the great friction to which portions were exposed in the violent treatment adopted by the miners in driving a jammed charge home.

Some little advantage was derived with the gun-cotton-rope charges from an increase in the amount of tamping which could be introduced into holes of a given length, owing to some reduction in the length of charge required as compared with powder; but the gain in this direction was greatly increased when the Austrian form of charge was replaced by compressed gun-cotton in 1868. The density of the former was = about 30 lbs. per cubic foot, while that of the latter was about 60 lbs.; this, and the difference in the form of the charges, caused the compressed gun-cotton to occupy somewhat less than half the space of the rope-charges; hence the blast-holes could be reduced in length and diameter, or a considerably larger amount of tamping could be used; or, if necessary, a larger charge of gun-cotton could be employed in any one operation. The smooth and hard exterior of the cylindrical charges of compressed gun-cotton rendered the operation of loading with them comparatively easy, and it was only in rugged and uneven holes that there was a liability of the charge to become jammed. Accidental ignitions and explosions have, however, occurred with compressed gun-cotton, in consequence of the great amount of violence used in forcing or driving home the charge. If it should happen to be ignited by powerful friction just as the force of a blow is spent and the jumper or driving-rod is being withdrawn, it will simply burn, but if the ignition takes place while the implement is pressing upon the charge, the full force of the operator being perhaps applied at the moment, the conditions are obviously the same as though the gun-cotton were firmly tamped, and a violent explosion must result. It is a question, however, whether, if wooden tamping-rods had been used in the place of metal tools, the accidents which have occurred in charging holes with gun-cotton might not

have been in great measure avoided. In addition to the advantages which have been pointed out as resulting from the production of compressed gun-cotton, there are some others which have a direct bearing upon its application to industrial purposes (Addenda, §§ 4–6). The employment of cotton waste in its production, in place of long staple cotton of high quality, which was required in the manufacture of the Austrian gun-cotton, and the important saving of time effected in the manufacture of mining charges, have led to a considerable cheapening of the material. The incorporation of at least ten hundredweight of gun-cotton at one time, in the purifying process which it undergoes after reduction to pulp, and before it is pressed into charges, gives rise to far greater uniformity than could possibly be attained, even with the most extreme care, when the products of separate small operations of manufacture were directly converted into charges. The circumstance that the compressed charges do not burn with the explosive violence exhibited by spun gun-cotton, even if they are confined in the packing-cases ordinarily used, renders the material much safer to store and handle, and has reduced considerably the chances of explosions resulting from the accidental ignition of the material during transport and in store. An additional and important element of safety arises from the superior efficiency of the purifying treatment to which the gun-cotton is subjected in the finely-divided form, as compared with the old system of washing the long fibres of gun-cotton (Addenda, § 5).

One of the chief advantages of compressed gun-cotton consists in the convenient and safe form in which the charges are furnished to the miners, who carry them about and handle them without fear or risk of accident; unfortunately, this advantage cannot but constitute occasionally an indirect source of danger, as an over-confidence in the safety of the material will lead the miner to forget at times that he is dealing with an explosive agent, and hence he will occasionally perform reckless acts in charging the blast holes, which must inevitably result in disaster.

One or two other special advantages have resulted from the conversion of gun-cotton into homogeneous compressed masses, but these will be dealt with more appropriately when the methods of applying the companion explosive agent, nitroglycerine, have been examined into.

Nitroglycerine has been raised from the position which, as already stated, it held for sixteen years as a rare and apparently useless chemical product to that of a most important industrial agent entirely through the skill, ingenuity, and perseverance of Mr.

Alfred Nobel. While repeated efforts were made to utilise gun-cotton and to perfect its manufacture, nitroglycerine continued to be regarded by chemists as akin to the chloride of nitrogen with respect to its uncontrollably dangerous character and its instability, and as being utterly unsusceptible of practical application, partly on account of the difficulty of bringing about its explosion by practicable methods, and partly on account of the great danger supposed to attend its manufacture and all manipulations connected with it.

At about the time when the Austrian improvements in the application of gun-cotton began to receive attention in England, Mr. Nobel made public his first attempts to apply nitroglycerine to practical purposes. In 1863 he proposed to add to the explosive power of gunpowder used in the ordinary way by impregnating the grains with nitroglycerine. This proposal was speedily followed by Mr. Nobel's discovery of a satisfactory method of developing the explosive force of nitroglycerine, either in its pure state or in admixture with other substances. The fact that nitroglycerine and analogous bodies are only slowly burned or gradually decomposed when brought into contact with an ignited body in the open air, unlike gunpowder and other explosive mixtures, led Mr. Nobel to conclude that it was necessary, in order to determine their explosion, to raise them, or some portion of them, rapidly to the temperature at which that result would be produced, and that if only a small portion were thus heated to the exploding point the explosion of the entire mass would be brought about (Addenda, §§ 20–30). In 1864 Mr. Nobel described several methods for raising portions of a charge of nitroglycerine to the temperature necessary for developing what he termed the initiative explosion; of these the really efficient one consisted in exploding a large percussion cap in contact with, or in close proximity to, the charge of nitroglycerine (Addenda, §§ 22, 23). It was found that the explosive metamorphosis proceeds with such almost instantaneous rapidity throughout the mass, from the portion in immediate proximity to the initiative agent, that confinement by tamping or other means is not required for the full development of the explosive force of nitroglycerine. The Author was led in 1867-8 to examine into the general question of the conditions which determine and regulate the explosion of compounds and mixtures, and did not find that Mr. Nobel's explanation of the development of detonation furnished a sufficiently satisfactory solution of many results obtained with nitroglycerine and other explosive agents (Addenda, §§ 24, 25); but there is no question that Mr. Nobel was the first to apply an initiative explo-

sion or detonation to the ready development of explosive force from substances which otherwise will not readily operate explosively, and that he was also the first to succeed in applying a liquid explosive agent to practical purposes.

While a mode of applying nitroglycerine was thus being established by Mr. Nobel, he also developed the manufacture and purification of the material to so great an extent that the grave doubts entertained within a recent period regarding the possibility of regularly producing it in a condition of purity and stability, which were fully warranted by the previous experience of chemists, have already given place to considerable confidence in the keeping properties of the substance (Addenda §§ 2, 11).

Nitroglycerine in its pure or undiluted condition was soon demonstrated to be the most powerful explosive agent yet made known. The economy in time and labour effected by its use in blasting and tunnelling in hard rock is undoubtedly greater, under favourable circumstances, than with gun-cotton or any of the most powerful substitutes for gunpowder. Moreover, the liquid form, high specific gravity, and insolubility in water of nitroglycerine, are peculiarly valuable properties under some circumstances; thus, blasting in wet holes, or actually under water, can be carried on with nitroglycerine expeditiously and without any special appliances. The efficiency of nitroglycerine as a mining agent having been established in Sweden and in Germany, demands soon arose for the material in other countries, and it has been extensively employed in mining districts abroad, especially in California. In Wales it was used by some quarry-owners as a most efficient agent for tunnelling and for removing the hard rock overlying the slate; but the liquid nature of the material, and one or two of its other properties, were soon found to constitute important sources of inconvenience and danger.

The poisonous nature of nitroglycerine, which injuriously affects the health of those handling and using it, is one of its defects. It is stated, however, that the human system may become accustomed to its influence, so that after a time the prejudicial effects on health, or the inconvenience attending the employment of nitroglycerine and its preparations, diminish or subside altogether. At any rate, there is no doubt that miners would not be deterred by these defects from availing themselves of the advantages presented by a powerful and efficient blasting agent. The comparatively high temperature at which nitroglycerine freezes, and the slowness with which it thaws, even at a normal

atmospheric temperature, constitute a source of inconvenience and, in some respects, of danger, though not perhaps in the particular direction in which many who have devoted attention to these subjects at first believed. The facility and violence with which a solid explosive agent will undergo detonation, when exposed to the operation of mechanical force, are in inverse proportion to the readiness with which the particles of the mass can yield to, or be moved by, the blow applied; thus, a highly-compressed mass of a fulminate-mixture can be exploded by a much lighter blow than a portion of the same mixture in the state of powder, because, in the latter case, the force of the blow is partly expended in mechanical work upon the loose particles of the mass struck. Similarly, therefore, it was believed that the yielding or mobile condition of the particles of a liquid must render it less susceptible to explosion by a blow or violent concussion than the same material in a solid condition. This view appeared, in the instance of nitroglycerine, to be supported by some fearful accidents which occurred in Sweden and in this country during the handling of frozen nitroglycerine. It has, however, been established beyond all doubt, that the material is much less susceptible to detonation in the frozen than in the liquid condition; the comparative inertness of the frozen substance constituting in fact, occasionally, a source of considerable inconvenience, In considering the behaviour of the substance when subjected, in the different physical conditions, to heat suddenly applied through the agency of friction or a blow, the fact was overlooked that the transformation of the liquid into gas must involve much less expenditure of heat than the same transformation of the solid, or frozen body; a circumstance to which the inferior sensitiveness of the latter to detonation must be, at any rate, mainly ascribed. The accidents which occurred with frozen nitroglycerine appear to have arisen from a recklessly rough usage of the material; and, so far as the apparently great safety or inertness of the frozen substance will lead to occasional recklessness, it does constitute a source of danger. The necessity for thawing the nitroglycerine (and its preparations) for use, unless exploding arrangements of a special character be provided, has also proved to be a source of accident; for though simple and safe regulations for thawing have been laid down and prominently insisted upon, it is impossible to guard against occasional mistakes, or against the deliberate thoughtlessness which is so fruitful of casualties with gunpowder in the mining districts, and is aptly illustrated by the recent well-authenticated case of a man who,

desiring to tap a powder-barrel, and being unable to find his auger, proceeded to bore a hole in the head of the cask with a red-hot poker.

The principal defect of nitroglycerine when employed in its pure state as a blasting material arises, however, from its liquid nature, and its consequent tendency to leak out of receptacles in which it is transported, stored or used. In blasting operations the nitroglycerine with which a hole is charged will flow into fissures in the rock, and may thus be conveyed to parts where its existence cannot be suspected, and where it may be afterwards accidentally exploded during the boring of other holes. Numerous more or less terrible nitroglycerine explosions have occurred in different parts of the world, the majority of which are considered to have been primarily due to the leakage of nitroglycerine from the packages in which it was transported and stored, notwithstanding the care with which these were constructed and packed. The great susceptibility of nitroglycerine in the liquid form to detonation, especially during hot weather or in tropical climates, would lead to the explosion of portions of the liquid which had escaped from the packages, by accidental concussion or comparatively slight blows, and thus disastrous explosions would be brought about. In order to reduce the chances of accident, Mr. Nobel adopted the ingenious precaution of dissolving nitroglycerine in wood-spirit, and diluting it with that solvent sufficiently to render the mixture quite non-explosive, the oil being easily separated, when required, by simple addition of water. But this precautionary measure was only partially successful, because the vapour of the highly volatile wood-spirit readily escaped from minute imperfections in the packages, and, as the spirit became weaker, an explosive mixture of nitroglycerine with a small proportion of spirit collected at the bottom of the vessel, the material thus being restored to a dangerous condition.

In the course of Mr. Nobel's persevering endeavours to counteract or reduce the sources of danger attending the use of nitroglycerine, he made the most important observation that the readiness or certainty with which it is exploded through the agency of a detonation is not reduced, but, on the contrary, somewhat favoured, by mixing the liquid with solid substances, in themselves thoroughly inert. This discovery led at once to the production by Nobel of solid, or more or less pasty, preparations of nitroglycerine, which, under the name of Dynamite, were first brought before the public in 1867, and the most perfect of which constitutes, as now manufactured, one of the safest, most powerful and most convenient explosive agents

applicable to industrial purposes. By the absorption of nitroglycerine by porous solids, or its mixture with non-absorbent solid bodies in a fine state of division, that substance is presented in a condition in which it may be manipulated like any solid explosive substance, with the additional advantage of plasticity; and if such a preparation is made according to the system now pursued by Nobel, it appears to set aside completely, or nearly so, all objections to nitroglycerine which could arise out of its liquid form. It is true that by diluting nitroglycerine with non-explosive substances, or even with other less powerful explosive materials, the force available from a given weight of substance becomes diminished; but the power of pure nitroglycerine is so much greater than that of gunpowder, that it will bear considerable dilution without important detriment to the high position which it holds among powerful agents.

The form in which Dynamite was first presented to the public, and the only form in which the Author had seen it before 1870, was that of a loose, soft, readily mouldable powder of a pink or buff colour, which consisted of about 75 parts of nitroglycerine held absorbed by 25 parts of a porous, infusorial, siliceous earth, known in German as "kieselguhr." The moist appearance of this powder favoured the opinion that the nitroglycerine would be liable to exude from it, or concentrate itself at the base of a package during transport or long-continued storage. The Dynamite, as thus supplied, was made up into cartridges by the miners, an operation which was attended with inconvenience on account of the absorption of nitroglycerine by the hands, and its consequent unpleasant effects upon the system. For some time past, however, dynamite has been furnished to the trade in the form of small cylindrical cartridges, consisting of the material in a compact condition enclosed in a single wrapping of parchment paper. These cartridges are consolidated by pressure, whereby any excess of nitroglycerine which the porous earth will not hold absorbed is expelled, and thus the separation of nitroglycerine during handling, transport, or exposure to elevated temperatures, appears effectually guarded against. The consistency of the dynamite charges is like that of dry putty, and the fingers are scarcely soiled with nitroglycerine when the uncovered charges are handled.

The kieselguhr selected as the medium for the application of nitroglycerine appears the material best calculated to hold absorbed a large proportion of the liquid, and to retain it even when the mixture is submitted to considerable pressure. When

dynamite factories were established in the outskirts of Paris during the late siege, and this particular siliceous earth could not be procured, a series of experiments was instituted for the purpose of discovering a good substitute; the most efficient absorbents next to this material were found to be precipitated silica, kaolin, tripoli, precipitated alumina, and sugar; but none of these appeared thoroughly equal to kieselguhr in their power of retaining a very large proportion of the oil.[1] Indeed, no other preparation has hitherto been proposed containing so large a proportion of nitroglycerine so safely applied as Mr. Nobel's so-called No. 1 dynamite. Another form known as No. 2, and containing a much smaller proportion of nitroglycerine, mixed with finely-powdered saltpetre and resin, or coal, is manufactured by Mr. Nobel as a cheaper blasting agent, for employment when the violent crushing and rending action of the stronger dynamite are not required.

Since the idea of incorporating nitroglycerine with solid substances was first conceived by Nobel, several preparations of that substance have been devised, in all of which the porous silica has been partly or entirely replaced by solid substances of an explosive or semi-explosive character. Among these, the following may be named as having received some amount of practical application: Colonia powder, which consists of a modified gunpowder, saturated with nitroglycerine, and is therefore very similar to the first nitroglycerine preparation devised by Nobel; Horsley's blasting powder, which consists of the chlorate of potash and nut-gall powder impregnated with 20 per cent. of nitroglycerine; Dualine, which may be described as Schultze's sawdust powder impregnated with nitroglycerine; Glyoxiline, which consists of a mixture of gun-cotton pulp and saltpetre, converted into porous pellets, which are saturated with nitroglycerine, and afterwards coated with varnish or other protective materials; and Lithofracteur, in which the siliceous earth and nitroglycerine of Nobel's dynamite are partly replaced by semi-explosive material, *i.e.*, by substances which fulfil the part of the gunpowder in colonia powder, or of the charcoal and saltpetre in Nobel's No. 2 dynamite. It need scarcely be said that all these preparations partake of the properties of the original dynamite, though they differ considerably in their nature. The first four consist entirely of explosive materials; of these, Horsley's powder and glyoxiline probably approach most nearly to dynamite in their explosive power.

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[1] The ashes of Boghead coal were eventually used for the production of Dynamite during the siege, as the best substitute for kieselguhr.

The preparation called Lithofracteur, for which considerable publicity has been obtained during the last twelve months, is stated to be a secret composition, at any rate in the form now introduced into this country. Some information as to its nature was, however, made public previously to its being brought forward in this country by the agents of Messrs. Krebs, of Cologne. In an interesting work by Lieutenant Trauzl,[1] Imperial Austrian Engineers, on the application of dynamite and gun-cotton, in which a decided preference is given to dynamite in most particulars as an explosive agent for industrial purposes, the chief defects of this material are stated to be the ready separation from it of nitroglycerine when in contact with water, and its tendency to freeze at comparatively high temperatures. It is pointed out that these defects are of minor consequence in the ordinary applications of the substance, but that they are of more importance in connection with large submarine operations and with its application to war-purposes. Lieutenant Trauzl further states that neither of the defects are overcome in the two other nitroglycerine-preparations then known in Germany, namely, dualine and lithofracteur. He describes the latter as being simply dynamite, in which an imperfect kind of gunpowder has been substituted for a proportion of the siliceous earth, and gives the following as the approximate percentage composition of the material: nitroglycerine, 52; siliceous earth and sand, 30; powdered coal, 12; nitrate of soda, 4; and sulphur, 2. Lieutenant Trauzl, when he visited this country in 1869, gave the Author a sample of lithofracteur which had been furnished him by Prussian officers; this was found to contain the substances above named in somewhat different proportions, and with the addition of a small quantity of sawdust. It is of course possible that the composition of lithofracteur may have since been again modified, and that the substance which has been used in experiments in the Nantmawr and Breidden quarries within the past year differs in some respects from the specimens about which there was no secrecy; but it has been publicly acknowledged by the manufacturers that the material is a modified dynamite, for which, however, special merits, in regard to power and safety, are claimed. With respect to power, it is difficult to conceive that a considerable proportion of the nitroglycerine contained in dynamite can be advantageously replaced

[1] "Explosive Nitrilverbindungen," &c., &c. Von Isidor Trauzl. Second Edition, 1870. Published in Vienna by Carl Gerold.

by a crude explosive mixture, which cannot but be less powerful in its action than that liquid: with regard to safety, it is obvious that the ready susceptibility of a particular nitroglycerine-preparation to explosion by blows or concussion is likely to be in direct proportion to the amount of nitroglycerine which it contains. The experiments made near Shrewsbury, in May, 1871, with lithofracteur, afforded satisfactory evidence of the safety of this material in transport, under circumstances likely to occur in practice, and a decided opinion to that effect was officially recorded by the Author at the time. Those results appear to have been fully confirmed by experiments recently carried out at Nantmawr in the presence of a Government committee. At present, however, there is no evidence that Nobel's dynamite would not successfully withstand similar practical tests to those carried out with lithofracteur; and, judging by the specimen of that substance handed to him by Lieutenant Trauzl, the Author believes that, at any rate in one respect, namely, the retention of the nitroglycerine at different temperatures, and under some conditions of transport, storage, and use, Nobel's dynamite possesses a decided superiority over lithofracteur. Actual practice on an extensive scale can, however, alone determine satisfactorily the relative value of these nitroglycerine-preparations.

In discussing the merits, as a mining and blasting agent, of gun-cotton in its most recent and compressed form, the employment of this material was considered in an earlier part of this Paper under precisely the same conditions as are fulfilled in the employment of powder. Compressed gun-cotton was however found by Mr. E. O. Brown, in 1868, to be susceptible of violent explosion through the agency of a detonation, like nitroglycerine and its preparations, one point of difference being that a more powerful and sharper detonation is required in the case of gun-cotton. When employed in the compressed form in this manner, gun-cotton becomes analogous in its behaviour and effects as an explosive agent to nitroglycerine; but the latter, in its pure condition, still appears to remain the more violent explosive substance. In ordinary blasting and quarrying operations where small charges are employed, the detonation of gun-cotton does not appear to present decided advantage over its explosion in the ordinary way, except in so far that hard tamping may be dispensed with, and that unsound holes may be successfully blown by detonation, while gun-cotton otherwise applied would probably fail in them. But in the employment of large charges, in submarine operations, in works of demolition, and others of a

military class, the explosion of gun-cotton by detonation presents important advantages, because its strong confinement may be entirely dispensed with, and, as in the case of nitroglycerine and its preparations, with some waste of power it may readily be made to operate most destructively without any confinement whatever. Thus, the rapid destruction of works and buildings, of stockades or bridges, the disintegration of boulders or other large masses of rock, the breaking-up of guns and other masses of metals, may be alike expeditiously accomplished by compressed gun-cotton and by nitroglycerine, dynamite, and similar preparations, the charges being either completely unconfined, or introduced into perforations which may be left open.

It may be expected that some definite statement should be given of the comparative effects, as mining and blasting agents, of gunpowder and of the violent explosive materials which have been more especially referred to. Excluding nitroglycerine in its pure or liquid form as pre-eminently dangerous, and therefore only likely to receive exceptional application, and taking dynamite and compressed gun-cotton as fairly representing the really useful explosive agents of the violent class, it may be stated, generally, that in all operations where rapid destruction is to be accomplished, as in the instances just referred to, gunpowder is incontestably inferior to those explosive agents. Not only would a much larger quantity of powder be required to produce similar results, but, in some instances, it would be impossible to perform the same operations even with exorbitantly large charges of powder. This is especially the case in the breaking up of masses of hard rock or metal by the superposition, or simple insertion into cavities, of the explosive agent. Again, in tunnelling and blasting in hard rock, the new explosive agents represented by dynamite and gun-cotton possess undoubted advantages. Important economy is effected by their use, not simply in regard to cost of material to produce equal effects, but in regard to saving of labour, of tools, and of time. Short charges and long tamping (which need not be hard tamping) insure the breaking up of the hole to the bottom, and generally tend to break up the rock beyond the bottom of the hole. The holes may be of smaller diameter, and are more rapidly loaded; the latter being especially the case with holes which are horizontal or driven at an upward angle.

Practical experience with compressed gun-cotton in North Wales, which no doubt also bears upon the employment of dynamite, has shown that in tunnelling in the slate quarries, where

sixty shillings per yard has to be paid when gunpowder is used, the same quantity of work can be done, and in less time, for forty-five shillings per yard.

The shattering and splitting effect of dynamite and gun-cotton in hard rock is much greater than with powder, but, in quarrying, the rock is generally not thrown off by them to the same extent. It is frequently found advantageous, in rapid working, to drive large and deep holes far back from the face, and charge these with the violent explosive, by which the rock is extensively fissured; large quantities of powder are then poured into the fissures, and by its explosion enormous quantities of rock are removed. In submarine blasting, a similar mode of combining the shattering and displacing effects of the violent and gradual explosive agents have been found very advantageous. In submarine demolitions, as in the destruction of wrecks, the violent explosives generally have a decided advantage; but in some operations upon iron ships, it has been found that the lifting effect of large charges of powder is advantageous in clearing away framework and other parts which have been shattered, but not actually removed, by the more violent explosive agents.

When a moderate cleaving and separating effect is required, accompanied by as little local action as possible, gunpowder cannot at present be advantageously replaced; as, for example, in the raising of large blocks of the finest slate. In other instances, of less frequent occurrence in industrial works, but which may be of some importance in military operations where great displacing action is required, gunpowder has the undoubted advantage. In the submarine blasting of very soft rock, such as soft limestone or chalk rock, the comparatively instantaneous action of the violent explosives operates disadvantageously in regard to their displacing power. As an illustration of this, some experiments made under Mr. Hawkshaw's direction in June, 1870, upon the foreshore near the Shakespeare tunnel, at Dover, may be referred to. The object was to ascertain whether the detonation of gun-cotton charges, placed upon the surfaces of submerged soft chalk rock, would break up the latter to such an extent as to facilitate its rapid removal by dredging. The results showed that the rock was completely disintegrated, or pounded into a plastic mass like clay, within a comparatively limited area; but that the shattering or rending of the rock did not extend to any considerable distance, as it would have done in the case of hard rock, of which the portions contiguous to the charge would have presented greater resistance to the blow exerted by the extremely

rapid explosion. Numerous experiments made in this and other countries with gun-cotton and dynamite have shown, that the violence of the concussion due to the suddenness of the explosion gives materials of this class important advantages over gunpowder for use in submarine mines.

Though it may be comparatively easy to point out, generally, the peculiar practical advantages which these violent explosive agents possess over gunpowder, it is exceedingly difficult, indeed impossible, in the existing state of knowledge, to give any precise information as to the equivalents of such materials as dynamite, gunpowder, gun-cotton, &c., or to state, even in regard to special applications, how much of the stronger explosive is really equivalent to a given weight of gunpowder or of some other material. Such statements are, however, constantly made, and with great confidence; thus the Author has even heard a particular nitroglycerine-preparation spoken of as having, in some rough experiments, produced a result ten per cent. better than that of another similar preparation. The serious difficulties have already been referred to which attend any attempts to institute a strict comparison between the destructive effects of different explosive agents, and there can be no doubt that, at any rate at present, long-continued use of two materials in the same class of work can alone determine their relative merits by the average results furnished. With regard to dynamite (which it is presumed may be considered certainly not inferior to lithofracteur) and compressed gun-cotton, it may be stated generally, but with reserve, that in ordinary blasting operations, the results furnished by them, weight for weight, are accepted as being about six times those produced by gunpowder. In comparing the effects of dynamite containing 75 per cent. of nitroglycerine with those of gun-cotton, the two materials appear to be practically on an equality as regards power, weight for weight; but dynamite has this advantage, which is shared by similar preparations, that, in rugged and uneven holes, a somewhat larger charge can be introduced into a given length of hole, because its plasticity permits of its being made by gentle pressure to completely fill the space allotted to the charge, while the rigid gun-cotton will not accommodate itself to irregularities in the shape of the hole. With regard to other special advantages of either of the explosives named, the most prominent one of dynamite is, that it may be used in a damp hole without fear of its missing fire; while, on the other hand, compressed gun-cotton possesses the advantages that it is not in any way injurious to handle, is not at all affected, in its ready explosiveness, by cold, and may, if necessary, be pre-

served for any length of time, without deterioration, in the damp and perfectly unignitable state (Addenda, § 6). With regard to the vapours evolved by the two materials in underground work, there is no question that both possess the advantage over gunpowder, and explosive mixtures analogous to it, of producing but little smoke; but if a hole should be overcharged, or if the explosion should be imperfect from any cause, then the vapours evolved in both instances are decidedly more objectionable than gunpowder-smoke.

In discussing the improvements which have of late years been effected in the production and application of explosive agents other than gunpowder, one cannot but be impressed with the great advance which has been made in a knowledge of the properties of some of these important industrial agents. The remarkable development which has taken place in the application of nitroglycerine affords a striking illustration of the manner in which chemical products, regarded for years as scientific curiosities, may start into importance; and encourages the belief that other organic derivatives, which are at present known but to few, as substances endowed with remarkable explosive properties, may yet become important rivals of gun-cotton and nitroglycerine. Some interesting results recently obtained by Dr. Sprengel indicate that new fields are possibly opening up already for the industrial application of compounds or mixtures not hitherto used as explosive agents. Dr. Sprengel has observed that mixtures of strong nitric acid with solid or liquid substances having a great tendency to combine energetically with oxygen, can be made to explode through the agency of a detonation, some of them producing violently destructive effects. He also finds that mixtures of readily oxidisable liquids with solid oxidisers, such as chlorate of potash, are similarly explosive. Thus, mixtures of bisulphide of carbon and chlorate of potash, of picric acid and of nitrobenzol with concentrated nitric acid, furnish powerfully explosive preparations, susceptible of detonation. It remains to be seen whether mixtures of this class can be applied with advantage as substitutes for the violent explosive agents which are now rapidly supplanting gunpowder in some of its important uses.

Even gunpowder can, however, be said not to have remained entirely passive in the general development which has recently taken place in the industrial application of explosive agents. Among the results of the experimental inquiry which the Author instituted four years ago, with the view of throwing light upon the nature

and cause of the phenomena exhibited by nitroglycerine and gun-cotton, when submitted to the action of a detonation, was the observation that all explosive compounds and mixtures, even including gunpowder, are susceptible of violent explosion through the agency of a detonation, though the nature and force of the required detonation vary considerably with different explosive substances. It was found that the full explosive force of gunpowder could be developed without a close confinement of the charge, by the employment of a sufficiently powerful detonating fuze; and a series of experiments, instituted during the demolition of works by the Royal Engineers at Chatham and at Portsmouth, indicated that decided advantages were attained by employing detonating fuzes for the explosion of charges of gunpowder which were not strongly confined. In submarine operations, the advantage of using a detonating fuze with gunpowder has been even more manifest, it being decisively proved that by their use the full explosive force of a large charge of powder could be developed without employing the very strong receptacles required for insuring its complete ignition when fired in the ordinary way. Some interesting results were also obtained in blasting experiments with gunpowder in which the charge was ignited at different distances from the top, and which indicated that, in blast-holes of considerable depth, decided advantage was gained by igniting the charge at or near the base, as the upper part then acted as additional tamping to the portion first ignited, and thus considerably increased the violence of the explosion (Addenda, § 21). These few points are briefly referred to with the object of indicating that it is not only in the application of substitutes for gunpowder that much has yet to be learnt, but that the whole subject of the application of explosive agents, generally, to industrial purposes is still a most fruitful one for patient investigation.

ADDENDA.

Composition and Production of Picric Acid, Nitroglycerine, and Gun-cotton.

§ 1. Picric acid, also called carbazotic acid, or trinitrophenic acid, may be obtained by the action of nitric acid upon indigo, aloes, silk, willow-bark, and a considerable variety of organic substances. It was first prepared in comparatively large quantities by Stenhouse, from the resin of *Xanthorrhœa hastilis*, the so-called Botany Bay gum. The ready production of phenol, or carbolic acid (the well-known antiseptic), from coal-tar, led to the manufacture of picric acid in large quantities by the action of nitric acid on that substance, and it has become an important article of commerce on account of its tinctorial properties, as it constitutes one of the best yellow dyes now in use. Its composition is represented by the formula $C_6H_3N_3O_7$; and it may be regarded as phenol, or carbolic acid, in which three atoms of hydrogen have been replaced by three molecules of nitric peroxide, as shown in the following comparison: $\left.\begin{matrix} C_6\ H_5 \\ H \end{matrix}\right\}$ O, Phenol; $C_6 \left.\begin{matrix} H_3 \\ 3\ N\ O_2 \end{matrix}\right\}$ O, Picric acid. This acid is a pale-yellow crystalline substance, sparingly soluble in water, but readily so in alcohol; it has a very bitter flavour, is not itself explosive, but burns readily with a somewhat smoky flame. Its salts are all explosive, especially the potash-salt, which is easily prepared. The highly detonating mixture which this furnishes with chlorate of potash appears to have been used in Paris by the Communists.

§ 2. Nitroglycerine, or glonoin, which was discovered by Sobrero in 1847, is a very pale-yellow, oily liquid, of specific gravity 1·6. It is inodorous, but has a sweetish pungent flavour, and when placed on the tongue speedily produces violent headache; similar effects result from handling it for a short time. It is very sparingly soluble in water, more so in alcohol, and dissolves readily in wood-spirit. Nitroglycerine is produced by the action of nitric acid in the cold upon glycerine, the sweet substance obtained when oils and fats are saponified, or exposed to a high temperature with water or steam. Its composition is expressed by the formula $C_3H_5 3(NO_2)\,O_3$, and it is formed by the substitution of three molecules of nitric proxide (NO_2) for three atoms of hydrogen in glycerine ($C_3H_8O_3$). It may be safely prepared by adding con-

centrated glycerine gradually to a cold mixture of one part of nitric acid, of specific gravity 1·52, and three parts of concentrated sulphuric acid, the mixture being kept cold by artificial means. When the proper proportion of glycerine has been introduced, the mixture being stirred during the addition, the latter is poured into water, which effects the separation of the nitroglycerine. Nobel recommends the addition of monohydrated nitric acid (or the mixture of the acids) to the glycerine in successive proportions, so that the temperature of the mixture does not at any time exceed 40°. The nitroglycerine separates on the surface of the acids, and may be separated by decantation ; it has to be purified by long-continued washing, special mechanical appliances and alkaline water being employed.

§ 3. Gun-cotton, pyroxilin, or trinitrocellulose, was discovered by Schönbein in 1845, and shortly afterwards, independently, by Böttger and Otto. When cotton-fibre or wood-fibre (cellulose) is submitted to the action of nitric acid, or of a mixture of nitric and sulphuric acids, at ordinary temperatures, it becomes endowed with explosive properties, a proportion of the hydrogen in the cellulose being replaced by an equivalent amount of nitric peroxide. The degree of nitration of the cellulose, and the consequent explosive power of the product, vary with the strength of the acids employed, and also with the temperature at which the converting operation is conducted. Gun-cotton proper, or trinitrocellulose, $C_6H_73(NO_2)O_5$, is the most highly explosive of those substances at present known, and, provided the manufacture be conducted with proper precautions, the product will contain only a small proportion of the less explosive nitro-compounds. Of these, at least two others have been proved to be definite products by Hadow; both are distinguished from the most explosive gun-cotton by their solubility in mixtures of alcohol and ether, and one of them is the comparatively feeble explosive material, and valuable agent in photography, known as collodion-cotton. At one time these less explosive products were believed to be more susceptible of chemical change, when exposed to heat, than trinitrocellulose; very careful experiments have, however, failed to establish any inferiority in this respect.

§ 4. The process of converting cotton into gun-cotton, as now practised, differs only in detail from the method prescribed by its discoverers ; certain precautions which are the result of experience, and a more thorough acquaintance with the nature of the material, have considerably improved the quality of the product in point of uniformity ; it is, however, in the purifying and subsequent manu-

facturing processes that improvements of the greatest importance have been effected.

§ 5. In the production of compressed gun-cotton, carefully selected cotton-waste is employed, in the place of the cotton-wool used in Schönbein's original process, and of the long staple cotton, spun into loose strands or threads, which was employed in von Lenk's system of manufacture. The cotton is first carefully picked over, and submitted to a preparatory cleansing process if necessary. It is then opened up in a teasing machine, and cut into suitable lengths, with the view of facilitating its rapid immersion and impregnation in the acid-bath. After having been thoroughly dried and allowed to cool in closed vessels, it is immersed, in small quantities at a time, in a perfectly cool mixture of one part of nitric acid (spec. grav. 1·52), and three parts of sulphuric acid (spec. grav. 1·85), and is afterwards allowed to remain for twenty-four hours in contact with about ten times its weight of the mixed acids, to insure as complete a conversion as possible into gun-cotton. The vessels containing the cotton and acids are kept closed, and as cool as practicable; and, at the expiration of the proper period, their contents are transferred to a centrifugal extracting apparatus, by which the gun-cotton is separated to a great extent from the excess of acid. It is then suddenly plunged, by means of simple mechanical arrangements, in small quantities at a time, into a large volume of water. The object aimed at is to dilute the acid which remains in the gun-cotton with water so quickly as to avoid the development of heat, and the consequent establishment thereby of a secondary oxidising action of the nitric acid upon the gun-cotton—an action which, if even of brief duration, might affect prejudicially the quality, and perhaps also the stability, of the product. The adoption of this precautionary measure, and the long-continued digestion of the gun-cotton with considerable excess of acids, constitute the prominent improvements which Baron von Lenk effected in Schönbein's process for producing gun-cotton. After this preliminary washing, the gun-cotton is drained of water by means of the centrifugal extractor; it is then rinsed twice in a large volume of water, and passed through the centrifugal machine after each rinsing. It is now transferred to a rag-engine of the kind ordinarily used in producing pulp for paper-making. By this operation the gun-cotton is reduced to the state of fine division necessary for its subsequent conversion into homogeneous compressed masses: it is subjected, at the same time, to a most searching purification, which is continued in the next operation, the pulp being transferred to "poaching" engines, where

it is beaten about in a large volume of slightly warm water, which is renewed from time to time. This final washing operation is carried on continuously until the gun-cotton has passed satisfactorily through a searching test of purity.[1] This method of washing constitutes one of the great advantages of the present system of manufacture. The chief obstacle to the complete purification of the gun-cotton consisted formerly in the obstinate retention of impurities within the hollow fibres. With a view to their removal, von Lenk prescribed continuous washing during many weeks in running water, and subsequent boiling with very dilute alkali. But by the application of the pulping and poaching processes, the capillary action of the fibre is greatly reduced, and the washing operation is rendered so searching that a decidedly more complete and uniform purification of the material is accomplished in three days, at the outside, than was previously attained by processes which extended over six or eight weeks. At the conclusion of the washing process, the gun-cotton pulp is impregnated with a small proportion of alkaline matter, and is then converted, by a preliminary moulding process, and subsequently by powerful hydraulic pressure, into compact masses of cylindrical and other forms, of about the same density as water, and of dimensions suited to the particular application required. During the whole of these manufacturing operations the gun-cotton is wet, and therefore absolutely uninflammable. After compression, the finished material is dried either in the open air or in heated chambers, where a rapid circulation of air is kept up. It is then packed in light wooden boxes for storage or transport. The drying process may be deferred for any time, and the damp, perfectly uninflammable gun-cotton stored in water-proof packages.

Considerations relating to Safety in Manufacture and in Storage of the more important Explosive Agents.

§ 6. The degree of safety with which explosive agents may be manufactured is an important question connected with their extensive application. The fact that the manufacture of gun-cotton as now carried on involves not the slightest risk of explosion up to the final stage, when the material has to be dried, distinguishes it from most other explosive agents. In gunpowder-

[1] An important improvement of a simple nature has quite recently been effected in this washing process by Mr. Abel, whereby the purification of the gun-cotton is greatly accelerated. It is now in course of elaboration at the Waltham Abbey works.

manufacture liability to explosion exists throughout all operations, from the point when the ingredients are mixed; and with regard to nitroglycerine and its preparations, it appears that, up to the present time, occasional severe accidents during manufacture have been inevitable; they probably arise chiefly from occasional neglect by the workmen of essential precautions in dealing with the explosive liquid, and it is difficult to see how they are to be effectually guarded against. The immunity enjoyed by gun-cotton is due to its being wet, and therefore absolutely uninflammable, throughout all stages, even after it has been compressed into cakes or disks. At this point it contains 15 per cent. of water, the expulsion of which by desiccation is unattended by any liability to explosion, or even to ignition, if simple precautions are adopted. For storing large quantities with absolute safety, it is convenient to preserve the compressed gun-cotton in the damp condition as it is delivered from the presses. It has been thus stored for long periods without the slightest detriment; and its non-inflammability in this condition is aptly illustrated by the fact, that the perforations required in some of the charges are produced by drilling the damp gun-cotton, the drill used revolving at the rate of about 600 revolutions per minute. The gun-cotton employed in some extensive experiments recently made on the South Coast had been stored damp for nearly nine months, and was dried partly in the open air, and partly in a hot-air chamber, when required for use. On that occasion 6 cwt. of the damp gun-cotton, packed in twenty-four strong wooden boxes, were stacked in a wooden shed, and surrounded by inflammable material. The building was then fired, and soon burned fiercely, which it continued to do for about half an hour, when the fire gradually subsided, and the building and its contents were entirely consumed. The gun-cotton must have burned slowly as the surfaces of the masses became sufficiently dry, as at no period of the experiment was any burst of flame, due to rapid ignition, perceptible.

§ 7. The possibility of extensively employing an explosive compound or mixture as a substitute for gunpowder, without special risk of casualties, is most intimately connected with the question of its stability. Mixtures of saltpetre or chlorate of potash with oxidisable substances of stable character may be generally relied upon to equal gunpowder in their unalterable nature under all conditions of storage and use in different climates; deterioration in explosive power by the absorption of moisture is the only prejudicial result which generally attends long-continued keeping of such mixtures. There are a few instances, however,

in which absorption of moisture may in time establish slight chemical action between the components of such mixtures, and thus become not only the cause of more serious deterioration, but also a source of danger, as chemical activity, once started in preparations of this kind, may gradually increase, being promoted by the heat developed, until it attains a violence resulting in the spontaneous ignition or explosion of the mass. Instances are on record of the spontaneous explosion from this cause of damp mixtures containing chlorate of potash, which have long been known to be perfectly stable when dry. Substances of organic origin, the stability of which is uncertain, require application with much greater caution to the production of explosive mixtures, as it is possible that changes may occur spontaneously in such substances, or may be established by natural atmospheric fluctuations of temperature, which may eventually give rise to an action between these materials and the oxidising agent with which they are mixed, resulting in ignition or explosion.

§ 8. Although the stability of compounds which are themselves endowed with explosive properties may appear perfectly reliable when they are in a chemically pure condition, it is susceptible of being seriously affected by comparatively minute causes; hence, the most scrupulous care in the production and purification of such substances is imperatively necessary. In this respect they compare disadvantageously with gunpowder, as a want of care in its production, though it may lead to accident during manufacture, or to an inferiority of the product, will not affect the stability of the material.

§ 9. Both nitroglycerine and gun-cotton, when prepared in small quantities and carefully purified, have been long known by chemists to be subject to very gradual chemical changes when exposed frequently to sunlight, and also to be liable to slow or rapid decomposition if exposed to temperatures considerably higher than occur as extremes under natural conditions in any climate. Both substances are also well known to have exhibited great stability under normal conditions of preservation, and even when continually exposed to light; but though many specimens exist which have remained unaltered almost since their first discovery a quarter of a century ago, the instances are numerous in which laboratory specimens have undergone spontaneous change with more or less rapidity.

§ 10. The apparently variable nature of those substances is due to the retention by them, in some instances, of small quantities of impurities, comparatively unstable in their character, derived from

foreign matters in the cotton or the glycerine; exposure to a high temperature or to sunlight may develop changes in them, resulting in the production of acid matters, the development of which may lead to the establishment of chemical change in the nitroglycerine or gun-cotton; hence they may constitute the germs of decomposition. Such impurities would be, to some extent, enclosed in the hollow fibres of gun-cotton, and can then only be removed effectually by a breaking-up of the latter, and long-continued washing; in nitroglycerine they would be held dissolved by the substance, and their removal can also be only effectually accomplished by reducing the liquid to a very fine state of division, and submitting it to protracted washing, with the aid of alkaline agents.

§ 11. For many years nitroglycerine was universally regarded as specially liable to spontaneous change. Even samples of different quantities of several pounds each, which, within the last four years, were produced at Woolwich in immediately successive operations, all apparently under the same conditions and with the special object in view of obtaining a thoroughly purified and stable material, have exhibited great differences in their keeping qualities. They have all been preserved in the dark, side by side; some are now in their originally pure condition, others have become more or less strongly acid, and two or three have undergone complete metamorphosis into oxalic acid and other products. The manufacturing and purifying processes, as perfected by Mr. Nobel, appear to furnish more reliably uniform products than those usually obtained on a small scale; and such specimens of these products as Mr. Abel has had an opportunity of examining have exhibited great stability. Yet, if it were possible to trace accidental explosions to their cause more frequently than is the case, an exceptional want of stability might perhaps have been found, in some instances at any rate, auxiliary in bringing about the violent nitroglycerine explosions which have occurred. It has, however, been already established, by extensive experience during the last three years, that nitroglycerine is a far more reliable material than was formerly believed, and that if the most scrupulous attention is paid to the purification, and is combined with vigilance during storage and use, and the adoption of certain precautions which have already been proved important safeguards against chemical change in materials of this class, the risk of accident is so greatly reduced as to warrant the extensive manufacture and employment of nitroglycerine-preparations under restrictions similar to such as may be deemed sufficient in the case of other explosive agents.

§ 12. The extensive experiments and observations which were set on foot nine years ago by the Government Committee, and have been continued to this day, on the keeping qualities of gun-cotton prepared by the Austrian process, have furnished most satisfactory results. Considerable quantities of gun-cotton, in a great variety of forms, have been stored at Woolwich for several years, and their periodical examination has failed to afford any reason whatever for doubting the stability of gun-cotton under all conditions of storage which are likely to occur. The experience thus gained applies even more favourably to gun-cotton reduced to pulp, according to the system lately in use, whereby the uniform purification of the substance is more effectually secured. Compressed gun-cotton has not only been stored extensively in different parts of Great Britain, but it has also been exported in considerable quantities to Australia, the West Indies, India, South America, and other distant countries, and has been used under circumstances specially trying to any material of uncertain stability.

§ 13. The explosions which occurred at Stowmarket ten months ago had the natural effect of dispelling from the public mind the great confidence which was becoming very generally entertained in the stability of gun-cotton. Fortunately, the facts which were elicited in the course of the inquiry constituted so complete a chain of evidence as to place the first cause of the explosion beyond any reasonable doubt, and to demonstrate that it was quite independent of any want of stability of the properly manufactured material. A supply of gun-cotton delivered from the works at Stowmarket, forming part of a quantity of which there remained a store in the magazines that exploded, was found to contain a proportion of disks in a highly impure condition. The amount of free (sulphuric) acid existing in some of these disks was so considerable that it could not possibly have been left in the gun-cotton after the first rough washing which it receives immediately on removal from the acid, and before conversion into pulp in the rag-engines, where it is beaten up for several hours with a large volume of water. Supposing, therefore, that the gun-cotton-pulp composing these disks had been submitted to the compressing process without being passed through the intermediate and principal purifying operation, it could not possibly have contained even a small proportion of the sulphuric acid which was discovered in the impure disks; and the same would have been the case even if the unpulped gun-cotton, after the preliminary washing and ringing, could have been converted into compressed disks. It was indisputably established, therefore, that the sulphuric acid discovered

in the impure gun-cotton, and which could not have been generated by any decomposition of the substance, must have found its way into the finished material in some manner totally unconnected with the process of manufacture, and that no amount of carelessness in manufacture, even to the extent of partial omission of the purifying processes, could have led to the existence of the acid found in the impure substance. That this impurity was sufficient to establish rapid change was sufficiently proved by the condition of some of the disks; and that this chemical change, accelerated as it was by the great heat of the weather at the time, gave rise to a development and accumulation of heat inevitably culminating in the ignition of some portion of the stored gun-cotton, was readily demonstrated by simple experiments with some of the impure disks themselves. But although the ignition of the store of gun-cotton in the lightly-built magazines at Stowmarket was completely accounted for, the very violent character of the explosions, and especially that of the second explosion of a small store which was burning for a considerable time before its contents detonated, were results quite unexpected to those well acquainted with the properties of gun-cotton in the compressed form.

§ 14. Many practical experiments had demonstrated that it might be submitted to extremely rough treatment without any risk of its explosion; and single packages of the closely-confined material had been repeatedly ignited, from within and without; no other result than an inflammation and a rapid burning of the gun-cotton having ever occurred. These demonstrations of the apparent immunity from explosive properties of compressed gun-cotton, unless strongly confined or fired by detonation, appeared to be fully confirmed by the results of a somewhat extensive experiment made at Woolwich a year ago, with gun-cotton packed in firmly-closed strong wooden boxes of the kind which Government proposed to use for storing the material. Eight such packages, each containing 28 lbs. of gun-cotton, were enclosed in a pile of similar boxes loaded to the same weight, and the contents of the centre box were ignited. No explosion resulted, and the contents of some of the boxes even escaped ignition. A second experiment, in which the centre box was surrounded by inflammable matter, so that a fierce fire burned within the heap for many minutes before the gun-cotton ignited, was also unattended by any approach to an explosion. The apparently conclusive nature of these experiments undoubtedly encouraged a false confidence in the non-liability to explosion of stores of gun-cotton in the event of accidental ignition; and the catastrophe

at Stowmarket demonstrated the imperative necessity for a more extensive investigation of the subject.

§ 15. The results of some experiments recently instituted near Hastings, by the Government Committee on gun-cotton, have already served to throw great light upon the manner in which the explosions at Stowmarket were brought about. In the first instance, twenty-four boxes (containing 6 cwt. of gun-cotton), of the kind used in the Woolwich experiments, were stored upon tables in a small wooden shed of light structure, and a heap of shavings and light wood was kindled immediately beneath the boxes, two of which were left partly open. After the fire had been burning for about seven minutes the gun-cotton inflamed, and continued to burn with rapidly increasing violence for nine seconds, when a sharp explosion occurred. A very similar result was furnished by a second experiment, in which the same number of boxes of gun-cotton was stored in a small magazine of stout brickwork. By subsequent comparative experiments it was judged that a considerable proportion of the gun-cotton had burned in both instances before the explosion occurred; but these were nevertheless of such violence as to produce large craters in the shingle on the site of the buildings, and to project the débris with much force to considerable distances. Two repetitions were afterwards made of the first experiment, in wooden sheds of similar structure, with corresponding quantities of gun-cotton, similarly arranged in boxes of the same size, and fastened down just as securely as those in the former experiment; but the boxes were made of somewhat thinner wood, and were constructed less strongly. In neither of these experiments did an explosion occur. In the one instance the fire was burning in the building for more than half an hour before the gun-cotton became ignited, and, three minutes after the first great blaze had subsided, there was a second blaze of gun-cotton. Although the latter must have been exposed to intense heat no explosion was produced. In the second experiment, the gun-cotton burned in three successive portions, the last having been exposed for many minutes to a fierce heat, yet burning non-explosively.

§ 16. The first two of these experiments demonstrated that if, in a store containing packages of gun-cotton in somewhat considerable number, the material became accidentally inflamed, the intense heat developed by the burning material in the first instance might raise some portion, still confined in boxes, to the inflaming point, and that then, the mass of the confined gun-cotton being in a heated condition, the ignition would proceed with such rapidity

as to develop the pressure essential to explosion while the gun-cotton was still confined, the resulting explosion being instantaneously transmitted to other boxes. When the magazines at Stowmarket exploded, a large volume of flame was observed to precede the explosion by a distinct interval. The two other experiments described appear to demonstrate that with such quantities as were stored in the experimental sheds, the fact of the material being confined in boxes of comparatively light structure constitutes a safeguard against explosion, the reason being that the weaker packages are opened up by comparatively feeble pressure from within; hence, when the contents of a box become raised to the inflaming temperature, or become ignited by the penetration of flame to the interior, the pressure developed by the first ignition is not sustained by the box to a sufficient extent, or for a sufficient time, to bring about explosion.

§ 17. On the occasion of the Stowmarket accident there were two store sheds, containing gun-cotton packed in boxes of light construction, which were ignited by the first explosion, and burned out without exploding; while a third, which contained gun-cotton packed in the strong Government boxes, exploded with great violence, after having been in flames for some time.

§ 18. Simple experiments serve to demonstrate that if any explosive compound or mixture be ignited when in a heated condition, it will burn with a violence proportionate to the temperature to which it has been raised. If this be near the exploding point, the result must be an explosion which will be violent in proportion to the degree of confinement of the material. A practical demonstration of this was furnished by an explosion which occurred at Woolwich in 1866. Several strong packages (metal-lined cases), filled with von Lenk's gun-cotton, some of which was purposely left impure, had been exposed for seven months to artificial heat in a strong brickwork chamber heated by steam. The impure gun-cotton in some of the packages was then known to be in a decomposing state, but the experiment was continued, and eventually spontaneous ignition occurred at a time when the boxes were heated to the maximum temperature. The result was a violent explosion of all the packages; the very strong confinement, and the heated condition of the gun-cotton which ignited, added to its being at the time in a state of chemical activity, determined its explosion; and the explosion of the other packages was a necessary consequence of the violent concussion to which they were exposed.

§ 19. There can be no doubt that the results of the recent expe-

riments and of those made last year, as also the results of the Stowmarket accident, have to be considered in relation to the quantities of gun-cotton operated upon, as well as to its confinement. The confinement of the eight strong packages by the layers of boxes which surrounded them on all sides, in the Woolwich experiment, was probably quite as great as that afforded by the light and roomy shed in which twenty-four boxes of the same kind were placed in double layers, in the South Coast experiment; yet in the latter case an explosion was developed, and not in the former with the smaller quantity. In the South Coast experiments, with 6 cwt. of gun-cotton, the explosions occurred eight seconds and ten seconds after the ignition of the gun-cotton; in the Stowmarket magazine, where several tons of gun-cotton were stored, the explosion appears to have almost immediately followed ignition; it must be borne in mind, however, that in this case much of the gun-cotton was closely confined by the large number of surrounding packages, and that the temperature of the gun-cotton was already raised considerably throughout by long-continued hot weather. Both of these circumstances must have greatly favoured the rapid development of explosion, independently of the much more intense heat generated by the rapid spreading of fire through a large proportion of the gun-cotton. The satisfactory results obtained in the South Coast experiments with the lightly-constructed boxes, with employment of 6 cwt. of material, appear to have received confirmation from the result of an accident which occurred in 1869 at Penryn, when a magazine of brickwork containing 20 cwt. of compressed gun-cotton, packed in boxes of light structure, was burned down without any explosion. But it is, nevertheless, very possible that a similar result would not be furnished by several tons of gun-cotton similarly packed; the much higher temperature which would be developed in that case by the first spreading of the fire, and the additional confinement, due to the larger number of packages, might combine to develop conditions favourable to the violent explosion of some portion of the mass, though no doubt a much larger proportion would burn non-explosively than if strong boxes were used. While, therefore, in strong dry gun-cotton, the probability that violent explosions will result from the accidental ignition of a magazine may be considerably diminished, or, at any rate, the violence of a possible explosion may be much reduced, by storing the material in packages of which some portions will yield readily to pressure from within, or by adopting any other storage arrangements whereby the rapid penetration of flame or heat between the compressed masses is

promoted, it must be considered as conclusively established by the last twelve months' experience, that such regulations as experience and prudence have rendered essential in connection with the storage of gunpowder and other explosive agents must also apply to the storage of compressed gun-cotton when in the dry state.

Conditions which determine and affect the Development of Force from Explosive Agents.

§ 20. The degree of rapidity with which an explosive substance undergoes metamorphosis, as also the nature and results of such change, are, in the greater number of instances, susceptible of several modifications by variation of the circumstances under which the conditions essential to chemical change are fulfilled.

Excellent illustrations of the modes by which such modifications may be brought about are furnished by gun-cotton, which may be made to burn very slowly, almost without flame; to inflame with great rapidity, but without development of great explosive force; or to exercise a violent destructive action, according as the mode of applying heat, the circumstances attending such application of heat, and the mechanical condition of the explosive agent, are modified.

§ 21. The character of explosion and the mechanical force developed, within given periods, by the metamorphosis of explosive mixtures such as gunpowder, is similarly subject to modifications; and even the most violent explosive compounds known (the mercury and silver fulminates, and the chloride and iodide of nitrogen) behave in very different ways, under the operation of heat or other disturbing influences, according to the circumstances which attend the metamorphosis of the explosive agent (*e. g.*, the position of the source of heat with reference to the mass of the substance to be exploded, or the extent of initial resistance opposed to the escape of the products of explosion). Thus, chloride of nitrogen, when covered with even a thin film of water, explodes with great violence when brought into contact with a decomposing agent; but if the covering of water is entirely removed, and the usual means are resorted to for causing the instantaneous decomposition of the liquid, its transformation into gases takes place with little or no explosive violence. Again, if a heap of fulminate of mercury be ignited at any portion of the exposed surface or immediately beneath it, the substance inflames with a dull explosion, and but little mechanical work is performed; but if the heap be ignited in the centre, or near the base, the explosion is very violent, and con-

siderable shattering effect is produced. In these instances, the covering of the water, on the one hand, and the external portions of the heap of fulminate, on the other, perform the functions of the tamping in a blast-hole, or of the walls of a shell, in determining accumulation of pressure and consequent development of violent explosion at the point of first ignition, which is then instantaneously transmitted throughout the mass. Applying this result to practical purposes, it is found that by igniting a charge of powder at or near the base in an ordinary blast-hole, considerable destructive effect can be developed without the use of any tamping, as the upper portion of the charge acts itself as tamping to the part first ignited, and develops its violent explosion. The destructive action is, of course, still further increased if tamping be employed under the above conditions.

§ 22. Nitroglycerine and analogous explosive compounds, which bear some resemblance to chloride of nitrogen in their power of sudden explosion, require the fulfilment of special conditions for the development of their explosive force. Thus, the explosion of nitroglycerine by the simple application of heat can only be accomplished if the source of heat be applied in such a way that chemical decomposition is established in some portion of the mass, and is favoured by the continued application of heat to that part. Under these circumstances, the chemical change proceeds with rapidly accelerating violence, and the sudden transformation, into gaseous products, of the heated portion eventually results—a transformation which is instantly communicated throughout the mass, so that confinement of the substance is not necessary to develop its full explosive force.

§ 23. The same result can be obtained more expeditiously, and with much greater certainty, by exposing the substance to the concussive action of a detonation produced by the ignition of a small quantity of fulminating powder, closely confined and placed in contact with, or in proximity to the explosive compound.

§ 24. The development of the violent explosive action of nitroglycerine, freely exposed to air, through the agency of a detonation, was for some time regarded as a peculiarity of that substance; it has, however, been demonstrated that gun-cotton and other explosive compounds and mixtures do not necessarily require confinement for the full development of their explosive force, but that this result is attainable (and very readily in some instances, especially in the case of gun-cotton) by means similar to those applied in the case of nitroglycerine.

§ 25. The manner in which a detonation operates in determining

the violent explosion of gun-cotton, nitroglycerine, &c., has been made the subject of careful investigation. It has been demonstrated experimentally, that the result cannot be ascribed to the direct operation of the heat developed by the chemical changes of the charge of detonating material used as the exploding agent. An experimental comparison of the mechanical force exerted by different explosive compounds, and by the same compound employed in different ways, has shown that the remarkable power possessed by the explosion of small quantities of certain bodies (the mercury and silver fulminates) to accomplish the detonation of gun-cotton, while comparatively large quantities of other highly explosive agents are incapable of producing that result, is generally accounted for satisfactorily by the difference in the amount of force suddenly brought to bear in the different instances upon some portion of the mass operated upon. Most generally, therefore, the degree of facility with which the detonation of a substance will develop similar change in a neighbouring explosive substance may be regarded as proportionate to the amount of force developed within the shortest period of time by that detonation; the latter being, in fact, analogous in its operation to that of a blow from a hammer, or of the impact of a projectile.

§ 26. Several remarkable results of an exceptional character have, however, been obtained, which indicate that the development of explosive force under the circumstances referred to is not always simply ascribable to the sudden operation of mechanical force. These were especially observed in the course of a comparison of the conditions essential to the detonation of gun-cotton and of nitroglycerine by means of particular explosive agents (chloride of nitrogen, &c.), as well as in an examination into the effects produced upon each other by the detonation of these two substances. In illustration, it may be instructive to give two examples. The detonation of compressed gun-cotton is accomplished by the explosion of 5 grains of confined fulminate of mercury, placed in contact with the mass, but it requires ten times that quantity of the violent explosive agent, chloride of nitrogen, also confined, to produce the same result. Again, the mechanical force exerted by the explosion of nitroglycerine is fully equal to that developed by the fulminate of mercury, yet a quantity of nitroglycerine, about seventy times greater than the minimum of the fulminate required to detonate compressed gun-cotton, fails, when exploded in contact with the latter, to produce any other result than the complete mechanical disintegration of the mass.

§ 27. The explanation offered of these exceptional results is to

the effect that the vibrations attendant upon a particular explosion, if synchronous with those which would result from the explosion of a neighbouring substance in a state of high chemical tension, will, by their tendency to develop those vibrations, either determine the explosion of that substance, or at any rate greatly aid the disturbing effect of mechanical force suddenly applied; while, in the instance of another explosion, which develops vibratory impulses of different character, the mechanical force applied through its agency has to operate with little or no aid; greater force, or a more powerful detonation, being therefore required in the latter instance to accomplish the same result.

§ 28. Instances of the apparently simultaneous explosion of numerous distinct and even somewhat widely separated masses of explosive substances (such as simultaneous explosions in several distinct buildings at powder-mills) do not unfrequently occur, in which the generation of a disruptive impulse by the first, or initiative explosion, which is communicated with extreme rapidity to contiguous masses of the same nature, appears much more likely to be the operating cause than that such simultaneous explosions should be brought about by the direct action of heat and mechanical force.

§ 29. With regard to the general manner in which a detonative action determines the violent explosion or sudden chemical disintegration of such a substance as gun-cotton, the similarity of its operation to that of a blow is readily demonstrated by many and simple experiments; one or two may be mentioned, which have been made with gun-cotton, and which probably illustrate the subject sufficiently for present purposes. The heat developed in a mass, when submitted to a blow, depends upon the resistance which its particles oppose (by reason of its rigidity or solidity) to the motion of the body striking it. Repeated blows may be required to explode a detonating substance placed in the form of loose powder upon an anvil; that force being, at first, in part expended in compressing the particles into a compact mass. When no longer free to move, the resistance they oppose to the force applied determines the sudden transformation of the latter into heat to a sufficient extent to bring about the detonation of the substance struck. If, in the case of gun-cotton, the force developed by a detonation, even of a powerful character, is allowed to operate upon the material in a loose, flocculent condition, the latter is simply dispersed; again, if the gun-cotton be only lightly compressed, a much more powerful detonation is required for its explosion than if it be in a very compact condition; and if the

mass of the highly-compressed material be only very small, it cannot be detonated by the means which are successful with larger masses, unless special precaution be taken, by fixing it rigidly to the detonating fuze, to prevent its being dispersed by the force which the explosion of the latter exerts. These facts, when compared with the following experiments, demonstrate that the general action of a detonation in developing the violent explosion of the substance upon which it is allowed to operate is that of a sudden blow given to some portion of a mass, the particles of which are in a condition to resist the motive or dispersive power of the mechanical force applied. A bullet from a Martini-Henry rifle was fired at a distance of about 50 yards against a slab of compressed gun-cotton 0·75 inch thick and 3·75 inches in diameter (weighing four ounces), freely suspended in air by a string: the gun-cotton was simply perforated by the bullet. A similar result was several times obtained with slabs of gun-cotton of the same dimensions, and with others double the thickness. On making the experiment with a slab of three times the thickness, the gun-cotton was inflamed but not detonated by the impact of the bullet. The mass was in this instance of sufficient thickness to offer considerable resistance to the penetrative power of the bullet; the passage of the latter was therefore retarded to such an extent as to give rise to the heating of the opposing gun-cotton particles up to their inflaming point. This experiment was repeated with the same result; but when a bullet was fired against a piece of compressed gun-cotton four times the thickness of that first employed, and weighing one pound, the result was detonation of the mass.

§ 30. It need scarcely be stated that the detonation of a large quantity of an explosive body is accomplished by the initiative detonation of a very small portion of the mass; this is the case even if the material is arranged in the form of a train of considerable length, the detonating fuze being applied at one extremity. Rows of gun-cotton disks, from 3 to 5 feet in length, with intervals of 0·5 inch and 1 inch between the individual masses, have been detonated in this way. There is, however, a limit to the distance to which a detonation will be transmitted along a row of spaced disks, the limit being determined by the particular weight of the masses employed; if it be exceeded, those masses which are at the farther extremity will be inflamed and scattered, instead of being detonated. A few preliminary experiments have been made with the view of determining, by means of Noble's chronoscope, the rapidity with which detonation progresses along a

row of gun-cotton disks. This will, no doubt, vary with the sizes of the masses. In an experiment with disks weighing two ounces each, placed in a row without intervals, it was found that the detonation extended to 3 feet in about one five-thousandth part of a second.

Recent Publications relating to Explosive Agents and their Application.

"Report on Gun-cotton," and Appendices. British Association Report. Newcastle, 1863.

"Report of Government Committee on Gun-cotton." Printed at the War Office. 1868.

"Reports relative to the Application of Gun-cotton to Mining and Quarrying Operations." Presented to the House of Commons, April 30, 1869. (179).

"Gun-cotton applied to Demolitions." By Colonel A. à C. Fisher, C.B., R.E. Proceedings of Royal United Service Institution, June 10th, 1870.

"Preliminary Report of the Special Committee on Gun-cotton, &c." December, 1871. Printed at the War Office.

"Manufacture and Composition of Gun-cotton." F. A. Abel. Transactions of the Royal Society. Vol. CLVI., 269. 1866.

"Dynamite, a Recent Preparation of Nitroglycerine." A. Nobel. British Association Report. Norwich, 1869.

"Explosive Nitrilverbindungen, insbesondere Dynamit und Schiesswolle, deren Eigenschaften und Verwendung in der Sprengtechnick." Von Isidor Trauzl, Ober-lieut. d. k. k. Geniecorps. Wien, Carl Gerold's Sohn, 1870. (2nd edition.)

"Explosive Compounds for Engineering Purposes," and "Recent Improvements in Explosive Compounds." By P. F. Nursey. Proceedings of Society of Engineers, February, 1869, and October, 1871.

"Employment of Dynamite at the Siege of Paris." "Engineering," May, 1871.

"Sur la Nitroglycerine et les Diverses Dynamites." Girard, Millot, et Vogt. Comptes Rendus LXXI., 688.

"De la Dynamite et de ses Applications au Point de Vue de la Guerre." P. Champion. Comptes Rendus LXXI., 728.

"Sur la Préparation Industrielle et les Propriétés de la Nitroglycerine." P. Champion. Comptes Rendus LXXIII., 42.

"Sur la Force de la Poudre et des Matières Explosives." M. Berthelot. Comptes Rendus LXXI., 619, 667, 677, 709, 940; LXXII., 165.

"Contributions to the History of Explosive Agents." F. A. Abel. Transactions Royal Society, CLIX., 489. 1869.

"On Recent Investigations and Applications of Explosive Agents." F. A. Abel. Edinburgh, Edmonston and Douglas, 1871.

"The Demolition of Wrecks under Water by Explosive Compounds." Lieut. H. Jekyll, R.E. Proceedings of Royal United Service Institution, May, 1869.

"On the Tension of Fired Gunpowder." Captain Noble, F.R.S. Spottiswoode and Co., 1871.

"Handbook of the Manufacture and Proof of Gunpowder." Captain F. M. Smith, R.A. Published by Authority. Eyre and Spottiswoode, 1870.

"The New Chemical Gunpowder (Sawdust-powder), and its Advantages over Black Gunpowder and its Substitutes." Captain E. Schultze. Asher and Co., 1865.

"Blasting Powder and its Surrogates; with Special Reference to a New Agent Manufactured by Krebs Brothers and Co., under the Name of Improved Lithofracteur." C. Lucknow, Deutz, November, 1869.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously—

"That, in order to insure a fuller attendance of members than could be obtained on Whitsun Tuesday, the Meeting be adjourned until Tuesday evening, the 28th of May."

May 28, 1872.

The Session was concluded by a CONVERSAZIONE, which was given by the President and Mrs. Hawksley, in the West Galleries of the Annual International Exhibition buildings at South Kensington, by permission of Her Majesty's Commissioners for the Exhibition of 1851. The section of the Exhibition opened to the visitors included the Machinery in Motion—this year devoted to Cotton, Paper, Printing, and Stationery machinery—and the British Picture Gallery. Some objects from the Scientific Inventions Court, and from other parts of the Exhibition, were likewise transferred for the occasion to the West Galleries. In addition to the members of all classes of the Institution, invitations were sent to, and were accepted by, a numerous circle of distinguished men of science and others; and in every case the card of invitation admitted a lady.

ADDITIONAL NOTICE.

THOMAS GRAY.

Mr. Edwin Chadwick, C.B., presented a bust of the late Mr. Thomas Gray, whom he described as a man of one idea, but that idea one of paramount importance, to which the better part of a very useful life had been devoted, with singleness of spirit and without any personal ambition.

Mr. Gray was originally a commercial traveller. Having in the course of his journeys seen a colliery iron tramway, he was impressed with the idea of adapting a modification of the system for the transport of passengers and goods. His opinions were made public in a volume,[1] (preserved in the Library of the Institution,) in which were detailed the disappointments he encountered on all sides—from the apathy of some, the interested views of others, and the general ignorance of the public. Nothing daunted, however, Mr. Gray, in 1820 and 1821, embodied his views in a petition to the Cabinet of the period, explaining the great advantages, and demonstrating the vast social and political importance, of the scheme. His applications even for a trial of the system for superseding stage coaches were useless. Few paid any attention to him; indeed he was regarded as a fanatic, and a visionary, although his views were very modest, as he only anticipated travelling from London to Liverpool or Manchester in twelve hours, and from London to Edinburgh in twenty-four hours. The proposal for carrying goods elicited some slight though languid interest; but it was only when there arose, in the minds of the cotton-brokers of Liverpool and of the manufacturers of Manchester, a sense of grievance at the tolls on the Bridgewater Canal,

[1] "Observations on a General Iron Railway, or Land Steam Conveyance; to supersede the necessity of Horses in all public vehicles: showing its vast superiority in every respect, over all the present pitiful methods of conveyance by turnpike-roads, canals, and coasting-traders. Containing every species of information relative to Railroads and Loco-motive Engines." By Thomas Gray. Fifth edition. 8vo. Maps and Plates. London: 1825.

that the idea of a Tramway or Railroad in opposition to the Canal was revived, and then chiefly by the statements in Mr. Gray's book. His views had, however, been mainly directed to passenger traffic, whereas their minds were solely fixed on the conveyance of goods, and on the defeat of the canal interests. Mr. Gray was, therefore, not called into council; and he was excluded from participating in the subsequent triumph of the Iron-ways of Great Britain. Although he was, undeniably, one of the earliest pioneers in the greatest works of the age, even his name had scarcely been mentioned in connection with this distinguishing feature of the period.

The bust of Mr. Gray, modelled by a brother of Mr. Chadwick—an amateur artist—was presented to The Institution of Civil Engineers as the fittest place for a record of a man who deserved better of his country.

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LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET
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